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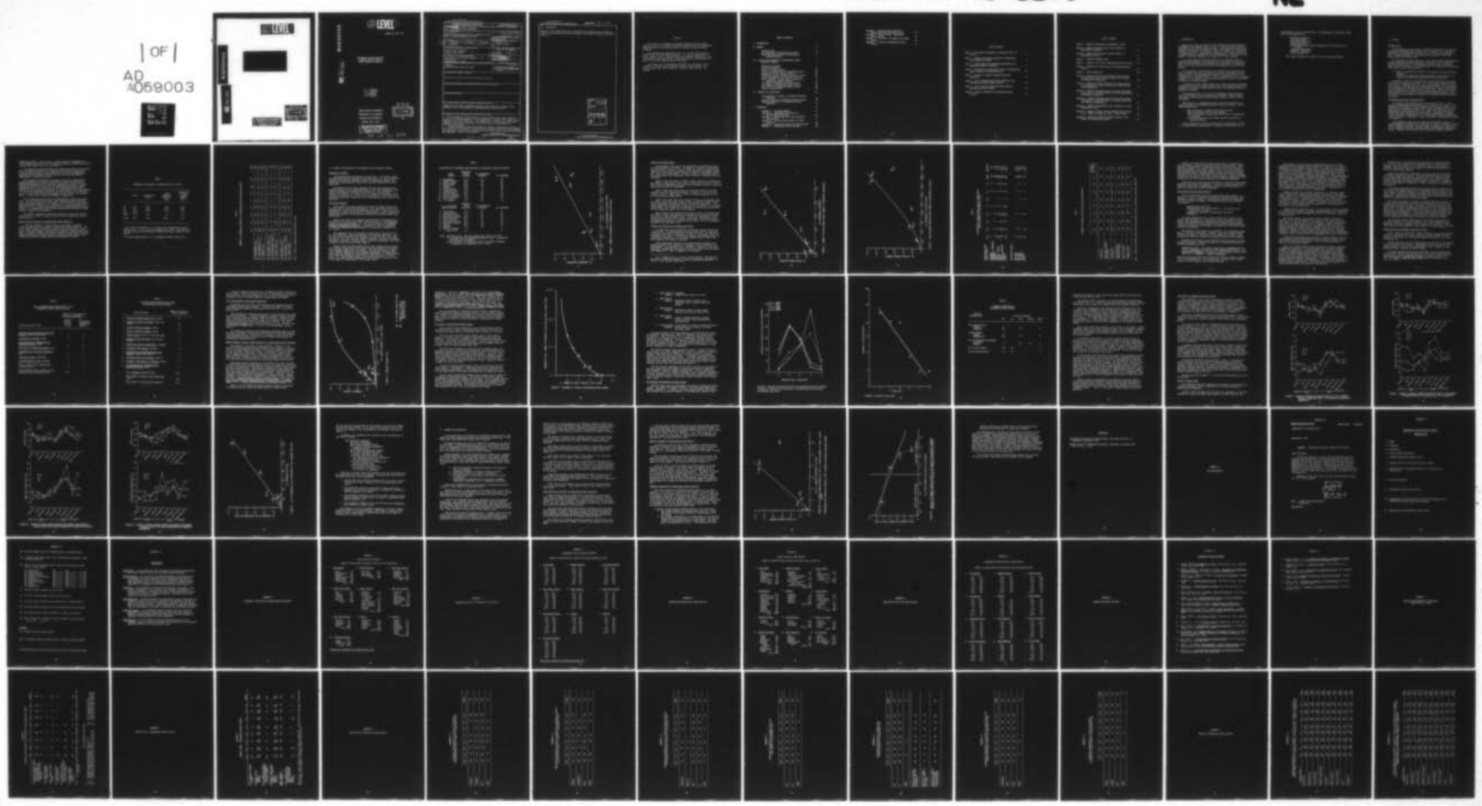

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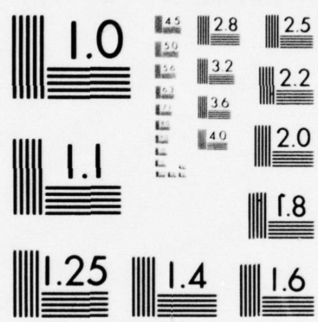

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Report No. HFE 76-2

ENGINEERING DESIGN EDUCATION IN AMERICA AND THE ROLE OF HUMAN RESOURCES VARIABLES

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The introduction of the concept of Life-Cycle Cost into design considerations has placed new emphasis on the integration of support costs (particularly manpower) into design decisions. The difficulties of dealing with downstream manpower costs in the design phase include the lack of such emphases in engineering education.

A study was done to assess the teaching of design in engineering education. 907 chairmen of departments of engineering were queried about their design (OVER)

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courses. The results show that considerably more emphasis may be needed on the teaching of design and on the inclusion of variables affecting downstream costs.

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PREFACE

This study of the education of design engineers has been undertaken as a part of a program of research on the nature of the engineering design process and the resultant impact of design on human resources variables.

This research was supported by the U. S. Air Force under Grant No. AFOSR 73-2569 to Wright State University. Dr. Charles Hutchinson was Project Monitor and Dr. Malcolm Ritchie was Principal Investigator. Helpful guidance was provided by Drs. Gordon Eckstrand and William Askren of the U. S. Air Force Human Resources Laboratory.

The authors wish to acknowledge gratefully the assistance of the following: Professor Russell Hannen, Professor George Hankins, Miss Patricia Vendt, Mrs. Doris Havens, Mrs. Patricia Elam, and Mrs. Jan Johnson.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

I. INTRODUCTION

Despite many years of research on the operability and maintainability of equipment, the manpower share of the U. S. Air Force dollar has been increasing faster than the equipment share. Human Resources research has resulted in principles of design, in reports of research, and in handbooks of design principles. Since manpower costs have still been increasing it is apparent that the information, its dissemination, or both have not been enough to influence adequately the design of Air Force equipment.

It is clear that the critical variables in the manpower costs of equipment are imbedded in the decisions which are made in the design process. The design itself will determine to a large extent how much manpower will be required over the life of the equipment for operation and support.

If the approach of writing reports of research and generating handbooks of design data has not worked, then one must look deeper into the design process. One fundamental influence on the design process is the background of the designer himself. In that background one of the important variables is the nature of the educational process by which the individual learned to be a design engineer.

It follows from this simple logical chain that some study of engineering education may yield insights leading to a better understanding of the designer, and perhaps to some insights leading to educational changes to improve the process.

The beginning place in this study of engineering education was an analysis of twenty-two design engineering textbooks. These textbooks were readily available and a study of their contents could be carried out easily.

There was still a considerable logical jump from the analysis of design textbooks to conclusions about the teaching of design. Some of these questions were:

What percentage of engineers take design courses?
What is the nature of the design courses?
Does the teaching of design vary with the type of engineering discipline?
What is the role (if any) of human resources variables in design education?

To get information to bear on these issues a questionnaire was sent to 907 departments of engineering in colleges and universities of the

United States, Canada, and Puerto Rico. The departments queried were those with the following titles:

- Aerospace Engineering
- Civil Engineering
- Electrical Engineering
- Engineering Design
- General Engineering (called "Engineering" in the body of this report)
- Industrial Engineering
- Mechanical Engineering
- Systems Engineering

This report documents the results of these two related studies.

II. METHODS

Textbook Study

The engineering design student is strongly influenced by the engineering design educational system of which he is a product. The materials (textbooks and supplementary readings) used in this system are thought to have a significant effect in the shaping of the designer's attitudes, design methods and effectiveness.

The objectives of this study were: (1) To gain a better understanding of the instructional materials presently being used in the teaching of engineering design and (2) To determine the emphasis that is placed on human resources information in these materials. The following two approaches were used to fulfill these objectives.

1. Review a representative sample (22) of general engineering design textbooks.
2. Interpret the engineering design education survey responses with regard to textbooks and supplementary reading materials.

An analysis of the type and content of twenty-two engineering design textbooks (see Appendix F) was made. They were selected using the following criteria: Copyright date after 1957; organizational basis and orientation; frequency of references in engineering literature; and availability. The following areas were reviewed for each textbook: author's background; tools; methodology for teaching design; design process(es) taught; traits, characteristics and attitudes of the competent design engineer; criteria for selection and evaluation, and emphasis on man-machine (human resources) information.

The Engineering Design Education Survey

An eighteen item questionnaire was distributed by mail. A copy of the entire questionnaire with definitions is presented in Appendix A. Six questions were designed to solicit information on the type, content, and objectives of the specific design course. Seven questions dealt with the methodology of design and the way it is taught. One nine-part question sought additional information on course content with emphasis on human resource variables (human factors). The questionnaire also included questions concerning the respondent's name, job position, department and college or university.

The respondent population was obtained from Pederson's Guide Inc. The questionnaire was mailed to 907 chairmen (by name or position) in United States, Canadian and Puerto Rican departments of mechanical, electrical, civil, aerospace, industrial, systems, general engineering and engineering design. Responses were requested from those faculty members teaching

engineering design in their courses. A minor source of respondents was a list composed by one of us (J. M. Howard) of authors of engineering design textbooks and journal articles on the subject.

The engineering fields surveyed were a subjective choice of the authors. While the work was supported by a grant from an Air Force organization, it was recognized that the survey should not be limited to Aeronautical Engineering; the importance of other fields to the Air Force effort is demonstrated by the data of Table 1.

Each engineering department chairperson was mailed a questionnaire package containing (1) a cover letter from the Wright State University Engineering Design Research Project that explained the purpose, the sponsorship and the method of reply for the questionnaire and that a single questionnaire was to be filled out for each engineering design course offered in their respective department; (2) three copies of the questionnaire; (3) a page with definitions for six of the nine selected topics (question 14); (4) a self-addressed postpaid envelope for the return of the questionnaires. (Items 2 and 3 above are presented in Appendix A.)

Only questionnaires more than 75% (approximately) complete were tabulated. If a questionnaire was from a multi-engineering field department (e.g., aerospace, mechanical, and nuclear), it was included in the earliest established engineering field (i.e. mechanical). Since respondents were asked to fill out a single questionnaire for each engineering design course offered, it is assumed that each returned questionnaire describes a design course as judged by the respondent.

The number of responses and courses reported in each field, varying from nine to 140, Table 2, should be kept in mind in judging the validity of the results.

Human Resources Variables in Engineering Design Education

A question addressed in these studies is the degree of emphasis placed on human resources variables in engineering design education. Some of the human resources variables of interest are maintainability, operability, safety and manpower (availability, capability, selection and training). An attempt to answer this question was made by reviewing what design textbook authors say on human factors as a design variable, and by interpreting the engineering design education questionnaire responses.

TABLE 1

PERCENTAGE OF ENGINEERS IN AEROSPACE WORK, BY FIELDS

	1968*	Lockheed-Ga.* 1974	AIAA* Membership Profile 1974	Aeronautical Systems Division WPAFB** 1975
EE	31.7	24.1	13.3	41.5
ME	28.5	24.6	34.0	18.5
AE	17.6	34.0	44.7	24.8
CE	8.8			
Other	13.2	17.2	8.1	15.1
Total	99.8	99.9	100.1	99.9

* "AE: Man in the Middle," J. J. Cornish III, Aeronautics and Astronautics, Vol. 13, No. 6, pp. 45-45 (June, 1975). Note: the source for the 1968 survey was the Engineering Manpower Committee, Engineers Joint Council.

** Private Communications, Dr. E. Gordhammer, ASD/ENO, WPAFB, Ohio.

TABLE 2

NUMBERS OF RESPONSES RECEIVED TO ENGINEERING DESIGN EDUCATION SURVEY

	M.E.	E.E.	A.E.	C.E.	E.	S.E.	E.D.	I.E.	TOTAL
NO. DEPARTMENTS (U.S.)	48	32	18	33	10	3	1	11	156
NO. QUESTIONNAIRES (U.S.)	104	61	27	95	17	8	21	21	354
NO. COURSES (U.S.)	110	65	27	111	18	8	21	21	381
NO. DEPARTMENTS (NON-U.S.)	12	4	-	2	-	1	1	1	21
NO. QUESTIONNAIRES (NON-U.S.)	30	8	-	8	-	1	2	1	50
NO. COURSES (NON-U.S.)	30	10	-	8	-	1	2	1	52
NO DEPARTMENTS (TOTAL)	60	36	18	35	10	4	2	12	177
NO. QUESTIONNAIRES (TOTAL)	134	69	27	103	17	9	23	22	404
NO. COURSES (TOTAL)	140	75	27	119	18	9	23	22	433

Note: Non-U.S. includes Canada and Puerto Rico.

III. RESULTS AND DISCUSSION OF ENGINEERING DESIGN EDUCATION STUDIES

Combining of Studies

The textbook study and analysis was done first. The results raised more questions and were incomplete and inconclusive as to what engineering students were actually learning in respect to engineering design. The engineering design education survey was a natural outgrowth of the textbook study.

The analyses of the survey responses not only gave insights on the questions raised in the introduction (page 1), but gave considerable additional information on textbook selection and use. To correlate the analyses of textbooks, the results of the two studies were merged. These results are discussed on a topical basis consistent with the interests of engineering education, rather than in the chronological order in which they were made.

The Survey Response

Four hundred four questionnaires describing 433 design courses were returned from 177 engineering departments. This represented returns from approximately 20 per cent of the departments solicited. Table 2 shows the respondents by number of departments, questionnaires, design courses and by engineering field for the United States and non-United States (Canada and Puerto Rico).

Table 3 shows that the respondent questionnaires were geographically representative, whether grouped into regions according to the Statistical Abstract of the United States, 1971, or by the sections of the American Society for Engineering Education. A breakdown of regions and sections by states and engineering field responses is presented in Appendices B, C, D, and E.

The respondents were, respectively, 40 per cent, 34 per cent and 16 per cent professors, associate professors and assistant professors. Six per cent of the respondents were chairmen or acting chairmen. The remaining four per cent were visiting, adjunct, affiliate, or consulting faculty, instructors, lecturers, associate deans, or were not identified. The effect of faculty rank is discussed below, page 29.

Figure 1 shows the approximately 20 per cent response and also shows the variation in response by field (those above the diagonal line responding in greater numbers than the average). The abscissa values in Figure 2 are sometimes approximate since programs administered by other departments, graduate programs not represented by departments, and administrative units other than departments make a precise count difficult. For this figure, the largest number appearing in three different listings was used as the number of "departments" in the United States.

TABLE 3

DISTRIBUTION OF RESPONDENT QUESTIONNAIRES BY GEOGRAPHIC REGION AND SECTION

ASEE SECTION	POPULATION (TOTAL) MILLIONS	NO. ENGINEERING COLLEGES	NO. RESPONSES
1. New England	11.8	30	50
2. Middle Atlantic	27.4	32	23
3. North Central	27.2	32	56
4. Southeastern	39.2	42	61
5. Midwest	12.9	16	26
6. North Midwest	17.4	7	39
7. Indiana/Illinois	16.3	18	17
8. Gulf-Southwest	15.9	25	22
9. Pacific Southwest	21.4	38	46
10. Pacific Northwest	11.2	13	34
11. Rocky Mountain	3.0	10	7
12. St. Lawrence	16.2	11	26

U. S. STATISTICAL ABSTRACT REGIONS	POPULATION (TOTAL) MILLIONS	NO. ENGINEERING COLLEGES	NO. RESPONSES
1. New England	11.8	30	50
2. Middle Atlantic	37.2	42	31
3. East-South Central	12.8	17	22
4. East-North Central	40.3	49	73
5. South Atlantic	30.7	35	42
6. West-North Central	16.3	16	36
7. West-South Central	19.3	29	27
8. Pacific	26.5	43	57
9. Mountain	8.3	20	17
10. Non-U.S. (Canada; Puerto Rico)	22.7		51

Notes: Population data: USA 1970, Canada 1966, Puerto Rico 1970.
No. colleges from 1973 Engineering Manpower Report, "Engineering and Technology Enrollments."
For composition of sections and regions and further breakdown of responses, see Appendices B, C, D, and E.

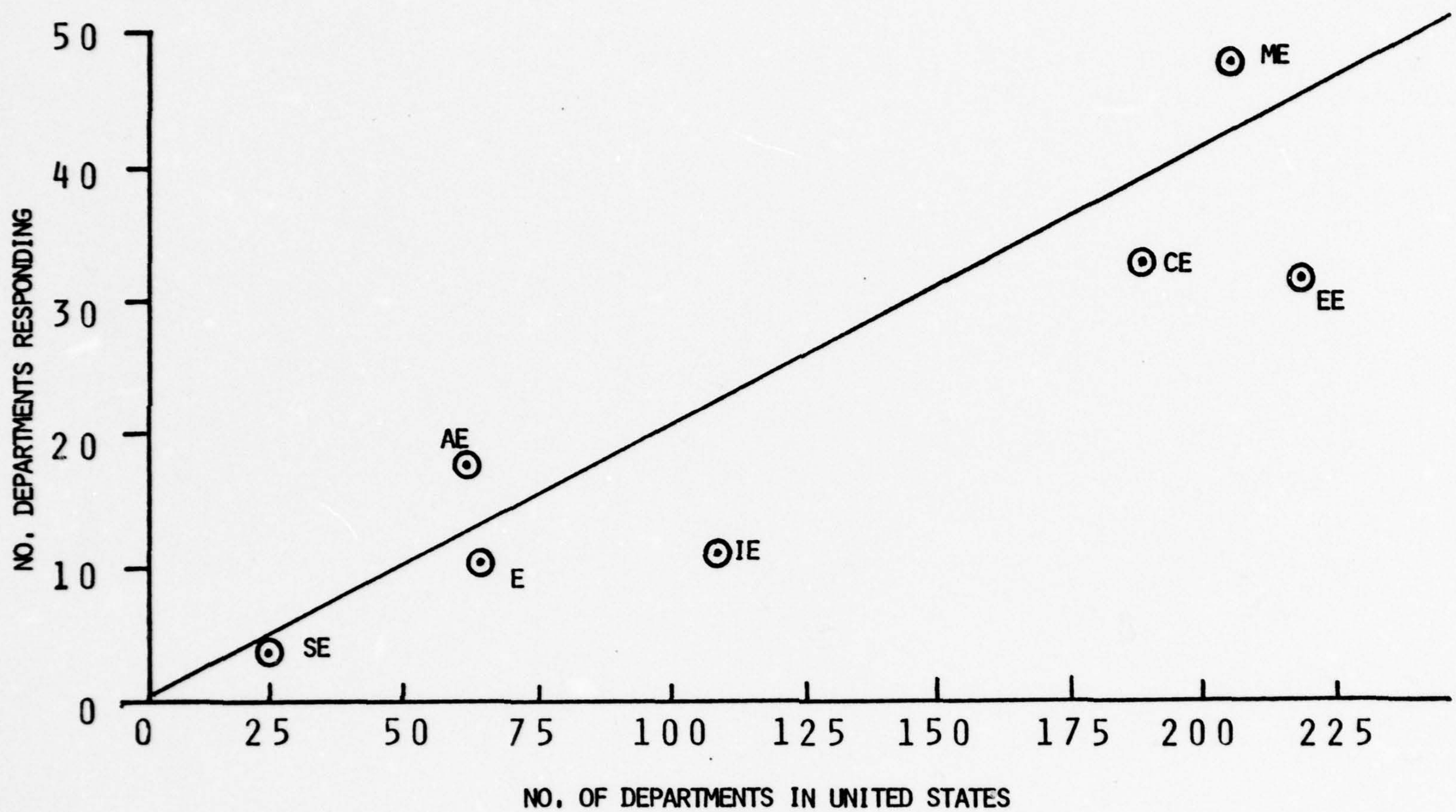

FIGURE 1. NUMBER OF DEPARTMENTS RESPONDING BY FIELD (USA).

Extent of Teaching Design

Approximately 20 per cent of the departments of engineering receiving the questionnaire responded. The number of responses by engineering field are given in Table 2. Figure 2 shows the number of design courses reported for each field plotted against the number of departments responding. There were approximately 2.2 design courses per department across all fields except Civil Engineering, which reported 3.4 design courses per department.

Figure 3 shows the number of design courses reported as a function of the number of departments in each field (a cross-plot of Figures 1 and 2). Here Industrial Engineering and Electrical Engineering show up as reporting fewer design courses per department.

Table 4 shows that the teaching of engineering design is directed primarily at senior engineering students. Overall, 73 per cent of the courses are for, or admit seniors, with this percentage going to 88 per cent for Electrical Engineering.

Table 4 also shows very little design activity at the freshman-sophomore level, with what little activity there is primarily located in Mechanical Engineering, Engineering Design, and General Engineering. This would suggest that the movement in the late 60's and early 70's to develop design courses for freshmen (as introductory and motivating experiences)* did not expand much beyond the initial efforts.

Some reviewers have suggested that design courses for freshmen might not appear in some fields because the students do not designate a major until later in their academic career. Many of the departments at these colleges would not give such courses for freshmen. This could explain the unusual distribution of freshmen design courses, but is an incomplete explanation for the small total.

Purposes and Objectives in Engineering Design

The objectives and philosophies of engineering design courses cover a broad range. The questionnaire provided a blank space for reporting objectives; there were no checklists or tables of objectives from which a respondent might choose. The objectives reported are probably those considered most significant or those having highest priority rather than every objective that might be included.

From a preliminary analysis of the questionnaire responses, six general categories were selected for grouping of course objectives and philosophies. The categories are: creativity; a practical, real-world experience; methodology; application of previous courses; work in groups; and communication. Table 5 summarizes the responses.

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*G. C. Beakley and T. W. Price, "Creative Design: One Method of Motivating Engineering Freshmen," Journal of Engineering Education, Vol. 58, No. 7, pp. 826-829, March 1968.

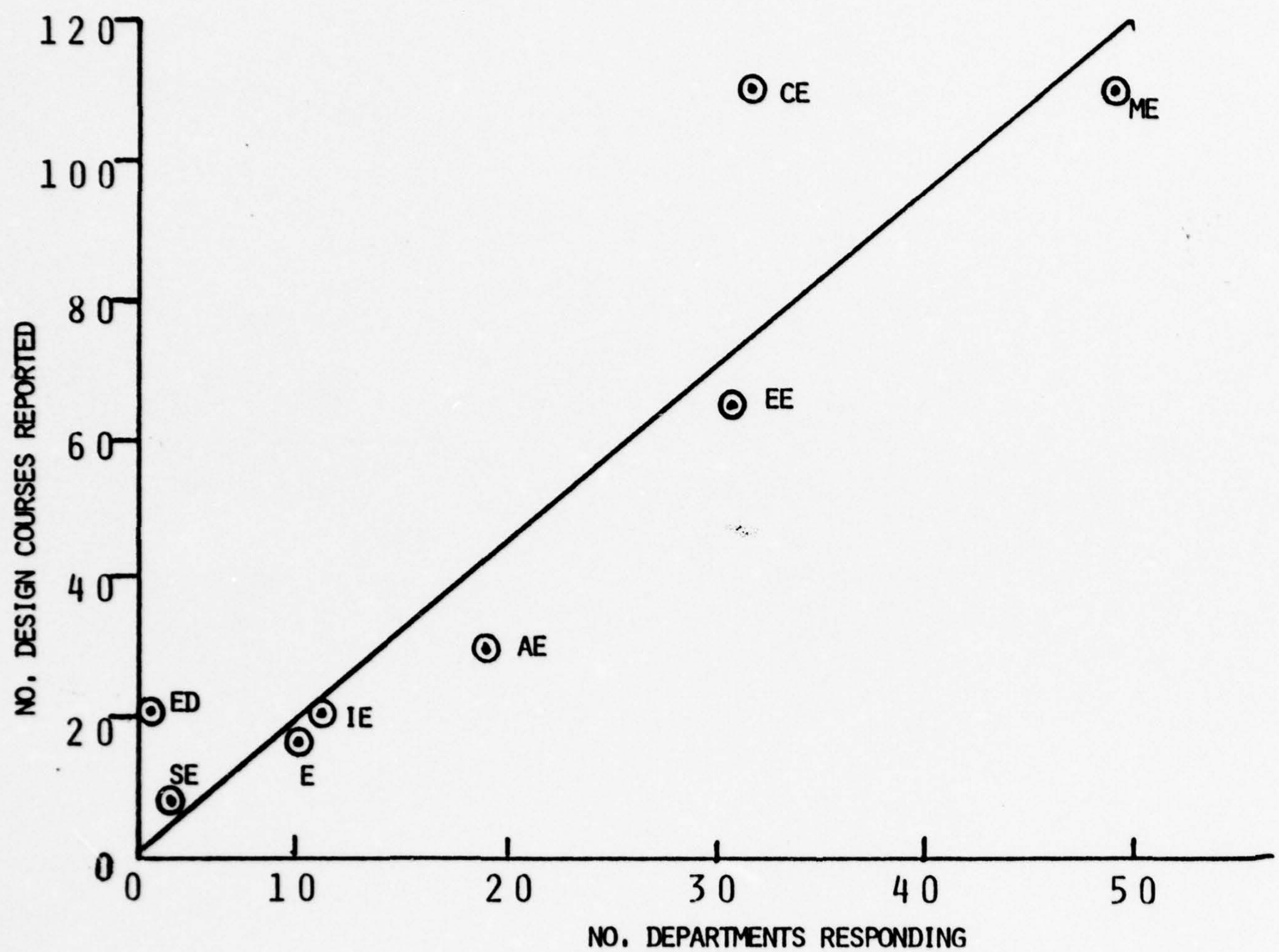


FIGURE 2. NUMBER OF DESIGN COURSES VERSUS NUMBER OF DEPARTMENTS RESPONDING.

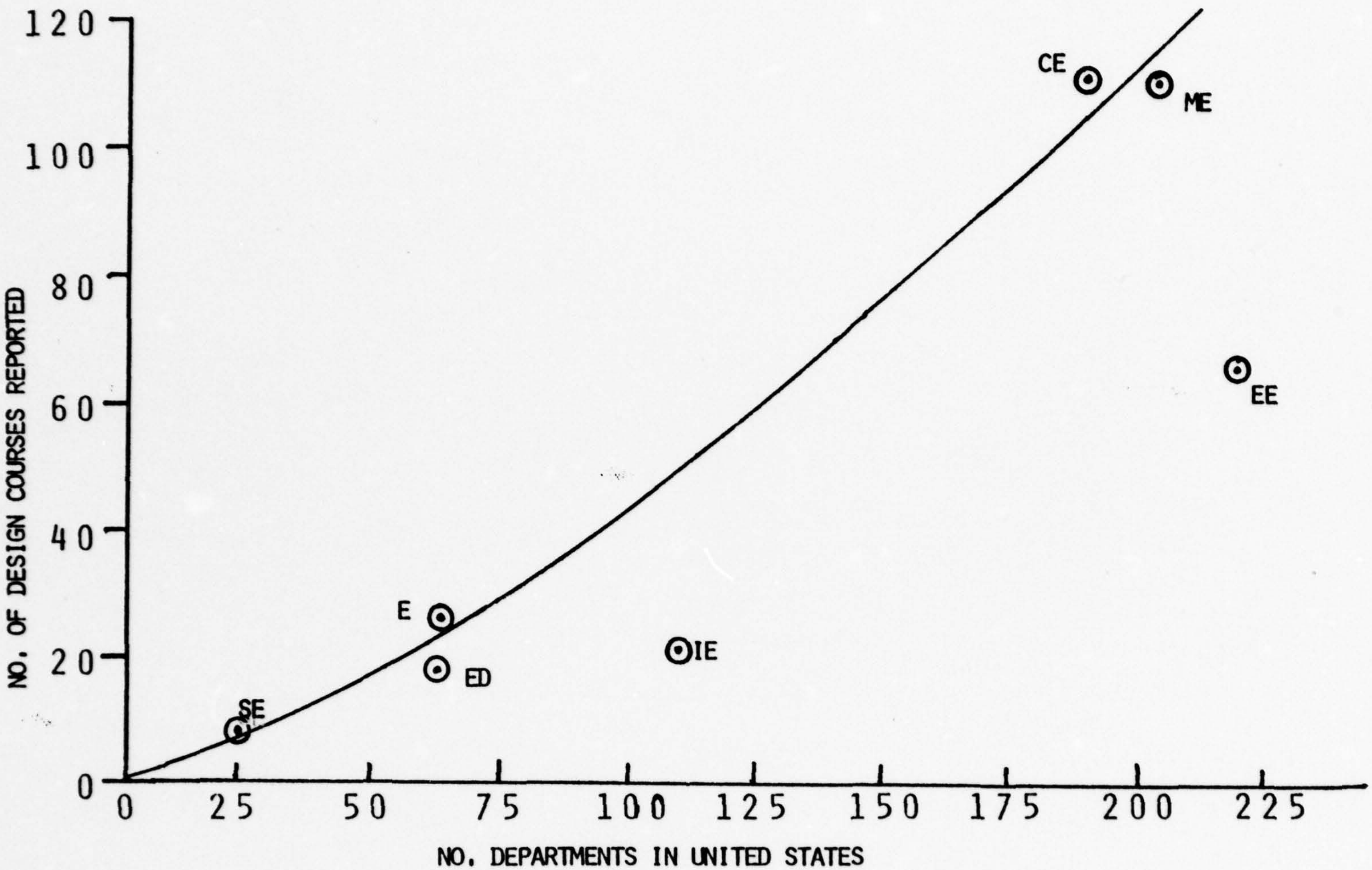


FIGURE 3. DESIGN COURSES REPORTED VERSUS NUMBER OF DEPARTMENTS BY FIELDS.

TABLE 4

DISTRIBUTION OF EDUCATIONAL LEVEL OF ENGINEERING
DESIGN COURSES BY ENGINEERING FIELD

EDUCATIONAL LEVEL UNITED STATES	M.E.	E.E.	A.E.	C.E.	E.	S.E.	E.D.	I.E.	TOTAL	PER CENT
FRESHMAN	6	-	-	1	3	-	4	1	15	4.0
FRESHMAN & SOPHOMORE	-	1	-	-	-	-	1	-	2	.5
SOPHOMORE	4	2	1	1	1	-	1	-	10	3.0
JUNIOR	15	2	-	9	1	-	-	3	30	8.0
JUNIOR & SENIOR	11	6	-	4	2	-	2	2	27	7.0
SENIOR	64	35	20	55	5	7	1	11	198	52.0
SENIOR & GRADUATE	3	16	1	26	1	1	7	2	57	15.0
GRADUATE	7	3	5	15	5	-	5	2	42	11.0
TOTAL	110	65	27	111	18	8	21	21	381	100.5
NON-UNITED STATES										
2ND YEAR	5	-	-	-	-	-	1	-	6	12.0
3RD YEAR	7	1	-	2	-	-	-	-	10	19.0
4TH YEAR	16	9	-	5	-	1	1	1	33	63.0
5TH YEAR	1	-	-	-	-	-	-	-	1	2.0
GRADUATE	1	-	-	1	-	-	-	-	2	4.0
TOTAL	30	10	-	8	-	1	2	1	52	100.0

TABLE 5

PERCENT OF COURSES CLAIMING PARTICULAR OBJECTIVES

	M.E.	E.E.	A.E.	C.E.	E.	S.E.	E.D.	I.E.	AVERAGE, ALL FIELDS
CREATIVITY	16%	8%	11%	3%	11%	0%	4%	5%	9%
PRACTICAL APPROACH, REAL WORLD	37%	44%	81%	39%	28%	67%	52%	55%	44%
METHODOLOGY	19%	12%	26%	9%	33%	44%	17%	9%	16%
APPLICATION OF PREVIOUS COURSES	52%	51%	19%	65%	56%	44%	57%	64%	54%
WORK IN GROUPS	11%	3%	22%	4%	22%	33%	17%	9%	10%
COMMUNICATION	11%	12%	30%	1%	11%	11%	4%	5%	9%

Note: Totals are greater than 100% because many courses claimed more than one objective.

Overall, more than half the design courses had as an objective to give the student a chance to apply the subjects he had studied. Almost half had as an objective the introducing of the student to real-world practical problems. This overall result held for all fields except Systems Engineering where practical problem solving was given first place with the application of college subjects second, and Aerospace Engineering where 81 per cent of the replies stated practical, real-world problem solving was an objective, while teaching the student to communicate (both written and oral) was given priority over the remaining objectives.

Creativity as an objective was mentioned in 9 per cent of all courses reporting, indicating a low emphasis. To give the student experience in working in groups and in communicating were also stated objectives, to about the same overall extent as creativity.

Engineering Design Textbook Analysis

Prior to initiating the survey of engineering design courses, an analysis was made of 22 selected textbooks on engineering design. These textbooks, listed in Appendix F, were selected with no prior knowledge of sales, adoptions, or usage. The selection was based on the following criteria:

> Copyright date after 1957.
> Organizational basis and orientation: All presented some methodology for design.
> Frequency of references in Engineering literature.
> Availability.

The areas reviewed for each of the 22 texts were: author's background; organizational basis; orientation; types of examples; types of design tools; methodology for teaching design; design processes taught; traits, characteristics and attitudes of the competent design engineer; criteria for selection and evaluation; and emphasis on man-machine (human resources) information.

The majority of the authors were professors in an engineering department at a college or university. However, there were a number holding positions in industry. An analysis of the effect of an author's background on the type and content of his design textbook was not attempted.

Textbooks have listed as many definitions and descriptions of design as there are authors. However, the majority of definitions include the following underlined key words:

> Engineering design - The activity whose various <u>techniques</u> and scientific <u>principles</u> are utilized to make <u>decisions with regard</u> to the <u>selection and placement</u> of materials to <u>form a system</u> or device which meets a set of <u>explicit</u> or <u>implied</u> <u>requirements</u>.

Design has been described as both simple and enormously complex, mathematical and non-mathematical, easy and difficult, and that it may involve either a trivial problem or one of great importance.

There appear to be four distinct organizational bases into which engineering design textbooks may be categorized. These are: (1) Process oriented texts, (2) Example oriented texts, (3) Component design texts, (4) Problem oriented texts. Process oriented texts provide a comprehensive description of a "generalized" model of the engineering design process, usually by devoting a single chapter to each individual step. The five basic steps in one approach to engineering design are: problem formulation, problem analysis, generation of design alternatives, decision and refinement, and evaluation. A wide variety of large-scale man-machine systems are exemplified in these texts (i.e., transportation, environmental, construction). Few of these texts, however, include a section on man as a design component. The "generalized" criteria that the authors emphasize in the evaluation of design alternatives (in order of importance) are: cost, safety, reliability and ease of maintenance.

Example oriented texts describe the analysis of a specific "single thread" (operation on a single input) and/or "high traffic" (multiplex input) system. The systems analyzed are mostly of the product, industrial or manufacturing type. A secondary orientation in this type of text is its direction toward a specific engineering field such as electrical, mechanical or product (small appliance). The authors stressed the following criteria for evaluation of design alternatives: cost, reliability, performance, time and innovation.

Component design texts deal mainly with the design of small components of a system such as controls, displays, mechanical gears, etc. These texts are also directed toward an engineering field like electrical, mechanical or manufacturing.

The fourth category, the problem oriented textbook, devotes the majority of each of its chapters to one specific area (tool) which the author feels is employed in the art of designing. Several reviewed texts fall solely into this category; however, nearly all texts had several chapters dealing with design tools. The following tools (listed by decreasing frequency) received the most emphasis in the 22 reviewed texts: probability, modeling, decision theory, optimization theory, computing, statistics, reliability, human engineering, simulation, linear programming, information theory, control theory, servomechanism theory and system logic.

Several design approaches are described in these textbooks. Some of these approaches share common characteristics and may be classified into three or four basic design processes. (Not all design approaches fit into this classification system.)

Some of the common characteristics shared by the various approaches to engineering design are (1) A conceptual process in which at least a fragment of a mental plan is necessary before the process can proceed; (2) An open ended problem-solving process in which there is no unique solution or correct answer; instead, there are several adequate answers some of which may be identified as "better" than others; (3) An analytical process requiring numerical computation; (4) A deductive process using differentiation by analysis for refinement; (5) An iterative probabilistic decision-making process which is often interdisciplinary in nature; (6) Normal operation under the stresses of time and cost.

By the nature of the design, the process used will differ depending on: the type, size, number of units and complexity of the system to be designed; the state of the art; the supporting personnel and equipment available; whether designed by one person or a team; and whether the system will include human interface.

Three basic categories of approaches to design have been classified: traditional, research and systems. The traditional approaches to design are oriented toward the design of components and their influence on the system, rather than toward the system as a whole. New systems designed by these approaches have evolved by incremental improvements in components and by the observation of weaknesses in order to minimize or eliminate any shortcomings.

The research approaches to design are oriented toward the analysis of the system. The design methodology for these approaches is similar to that of the general scientific method for the following: observation and literature review (identify the problem); hypothesis formulation (subdivide into components); experimentation (analyze the components); and conclusion (synthesize the components into the desired system).

The systems approaches to design are oriented toward the creation of a total system, taking into consideration the characteristics of and the interactions between subsystems. All details of the final working system must be foreseen since a prototype must come into being at one time rather than evolve. Of course, evolutionary improvement is still important since even the most advanced design is based on the use of already designed, developed and proven components. The systems method mainly provides a means for the orderly, integrated and timely design of systems and probably is the most applicable in the design of large scale man-machine systems.

The subsequent study of engineering design education disclosed that the texts selected for the above analysis, i.e., texts teaching design methodology, were not in general the most popular with educators. Table 6 lists the texts which appeared in both studies, with their frequency of use.

Engineering Design Textbooks Reported by Survey

Table 7 gives the twelve most popular textbooks for engineering design courses as reported in the survey. Only two of these, numbers 9 and 12 (Table 7), were among the 22 originally selected for analysis (see Table 6 and Appendix F).

Table 7 also shows the very large variety of texts in use, 191 separate titles specified for 320 courses. Approximately one quarter of the 433 courses reported in the survey did not specify a text. Appendix G gives additional data, by fields, on textbook usage.

No single engineering design text was found to be used across engineering fields. However, the following texts were listed in more than two engineering fields: Introduction to Design, M. Asimow, 1962 (M.S., E., S.E.) and Design--Serving the Needs of Man, Beakley and Chilton, 1971 (M.E., E., I.E.).

TABLE 6

USE OF TEXTBOOKS WHICH WERE STUDIED IN THE
ENGINEERING DESIGN TEXTBOOK ANALYSIS

Title and Author of Text	Number of times specified by survey respondents: As the textbook for the course	As recommended supplemental reading
Introduction to Engineering Design and Graphics, Beakley and Chilton	5	0
Introduction to Design, Asimow	3	3
An Introduction to Engineering and Engineering Design, Krick	4	0
The Science of Engineering Design, Hill	3	0
A Methodology for Systems Engineering, Hall	0	2
Engineering Design, Middendorf	1	1
System Engineering Tools, Chestnut	1	0
Other 15 texts used in Engineering Textbook Analysis	0	0
Total different texts specified in the engineering design education study	191	-

TABLE 7

THE TWELVE TEXTS SPECIFIED MOST OFTEN
FOR ENGINEERING DESIGN COURSES

	Title and Author	Number of courses in which specified
1.	Mechanical Engineering Design, Shigley	26
2.	Design of Concrete Structure, Winter and Nilson	13
3.	Design of Machine Elements, Faires	10
4.	Design of Machine Elements, Spotts	8
5.	Machine Design (3rd Ed.), Black and Adams	7
6.	Design of Steel Structures, Gaylord and Gaylord	7
7.	Reinforced Concrete Fundamentals, Ferguson	6
8.	Structural Steel Design, McCormac	6
9.	Introduction to Engineering Design and Graphics, Beakley and Chilton	5
10.	Foundation Analysis and Design, Bowles	4
11.	Kinematics and Dynamics of Machines, Martin	4
12.	An Introduction to Engineering and Engineering Design, Krick	4
	Total different textbook titles	191
	Total number of design courses specifying a text	320
	Total number of design courses reported	433

A plot of number of text titles vs. the number of design courses, by field, Figure 4, shows an initial slope of 0.74, equivalent to 1.35 courses per text title. This curve flattens out at a level of approximately 50 (different titles) for fields reporting a large number of courses.

Use of Supplemental Instructional Materials

An average of 76 per cent of the design courses reported the use of supplemental instructional materials. By field, the number of courses using supplemental materials varied from 67 per cent (S.E., E.D.) to 89 per cent (E.).

The supplementary reading materials may be classified into the following general categories: textbooks, magazines, journals, manuals and handbooks, catalogs, codes and company product literature. A variety of textbooks were listed with the majority being of the "example" and "problem" oriented organizational basis (see discussion on page 16). The text, Introduction to Design (Asimow, 1962) was found to be the only one listed by two fields of engineering (M.E. and S.E.) as supplementary reading material.

The Mechanical Engineering and Engineering departments appear to make more use of textbooks; the Electrical Engineering and Industrial Engineering departments appear to make more use of journals; and the Civil Engineering departments appear to make more use of manuals and handbooks as supplementary reading materials.

Human Variables, Factors, and/or Resources in Engineering Design Textbooks

How prominent is the role of human variables in design? In the review of the 22 engineering design textbooks, major reference or description of the human resources involved in the design variables was included in less than 40% of these texts. This is a function of several factors: (1) the engineering orientation of texts that describe design for non-human interfaced systems; (2) the attitudes and assumptions of authors about the value of human resources as a design variable; and (3) the lack of or difficulty in locating specific quantitative human resources data.

When human resources information was included in the texts reviewed, it usually dealt with the human factors areas of the sensory and motor capabilities and limitations of the operator, fatigue, operator station layout and time and motion study. When the terms "manpower or human resources" were used, they referred usually to the general project organization and staff requirements (administration and supervision). There were very few references to maintainability requirements in design textbooks. Usually included in the human factors information was reference to the following data books: Human Engineering Guide to Equipment Design (1963), U.S. Air Force Personnel Subsystem Design Handbook, The Human Body in Equipment Design (1966), and Human Engineering Guide for Equipment Designs (1964).

Three of the 191 engineering design textbooks listed by instructors of engineering design courses pertained directly to human factors

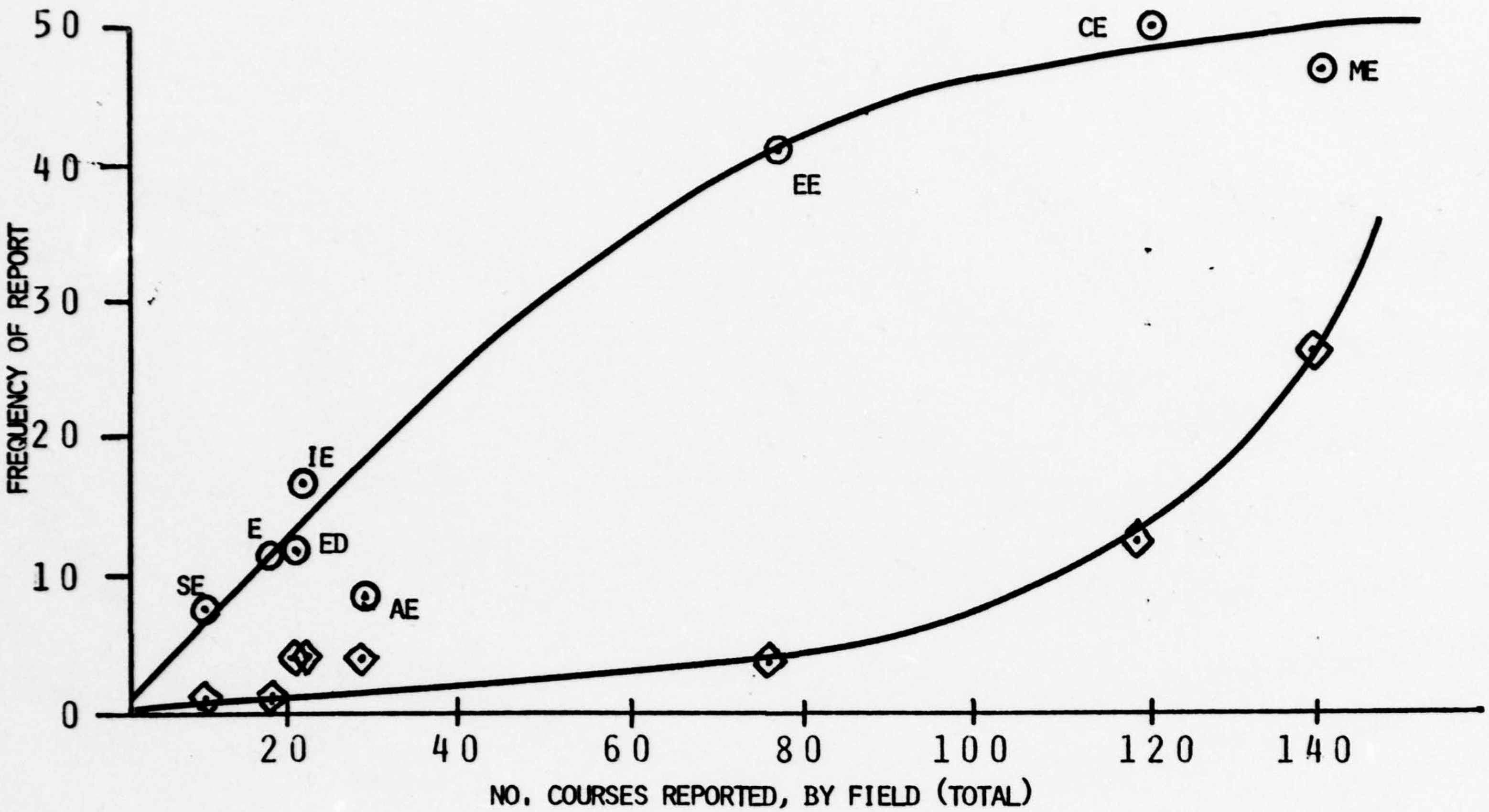
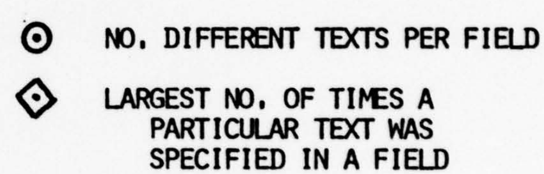


FIGURE 4. TEXTBOOK FREQUENCY DATA.



engineering. They were: Ergonomics, by Murrell (1972); Human Factors Engineering by McCormick (1970); and Human Engineering Guide to Equipment Design by Van Cott and Kinkade (1963). All three were listed as used in Industrial Engineering department courses. Some other textbooks (mostly in the general category) were found to have a chapter section devoted to the area of human factors engineering. Some of these texts were: An Introduction to Engineering and Engineering Design by Krick (1969); The Science of Engineering Design by Hill (1970); Systems Research and Design by D. P. Eckman (ed.) (1961); and Engineering Design by Middendorf (1969).

Only one department of engineering design listed as supplementary reading materials textbooks pertaining directly to human factors engineering. However, both Engineering Design and Industrial Engineering departments listed the journals of the Human Factors Society, and the Ergonomics Society and the Journal of Applied Ergonomics as supplementary reading materials.

The Nature of Engineering Design Courses

Course titles, project titles and scope of student design projects tell much about the nature of engineering design courses, for each, like a newspaper headline, tells in a few words what the course is all about.

The first thing one notices about design courses is the variety. Design is a process, which is taught by application in many fields and subfields. The variety is indicated by Figure 5 showing the frequency with which a particular course title appears. Only one single course title is used as many as seven or eight times (none more than eight) while 296 separate titles are each used one single time.

The word "design" appears in 74 per cent of the course titles. Of particular interest, only Electrical Engineering, Systems Engineering and Mechanical Engineering have laboratory design courses. The survey was not detailed enough to detect whether these were design by a hands-on, practical, experimental approach, or whether the lab was a scheduled exercise in planning, analyzing, coordinating and the other desk work that goes into design, or whether some other approach was used. Appendix H presents a summary of course title data.

Of the 417 different design course titles given, only five used the terms "human" or "man-machine." These five courses were listed by Industrial Engineering departments (2) and Engineering Design departments (3). All five human factors type courses were given only to juniors and seniors.

Data on course prerequisites offered little insight into the nature of the teaching of engineering design. The variety of the courses, and the predominately senior level at which they are taught, led to a general description of the undergraduate curriculum in that field as the prerequisite for an engineering design course. One or more projects were required in 79 per cent of the courses reported. On the basis of project title the projects were evaluated for size. Five size categories were chosen:

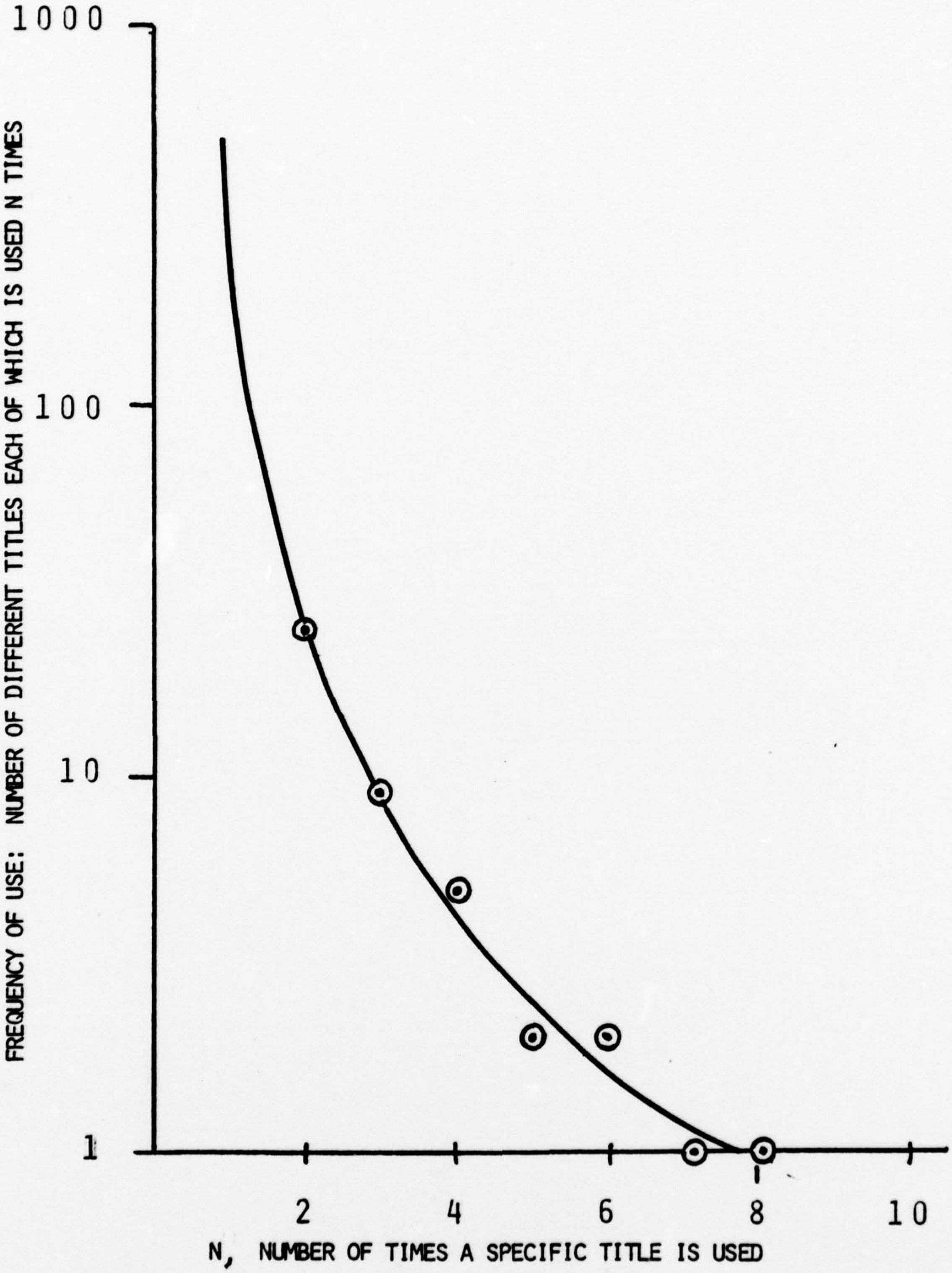


FIGURE 5. FREQUENCY OF TITLES OF ENGINEERING DESIGN COURSES.

1. Small object or component.
   Examples: stepped shaft; girder; sun visor.

2. Small device.
   Examples: mechanical clutch; building floor; electrical heater; speaker cross-over network.

3. Medium device.
   Examples: motorcycle; glider; building frame; high pass and low pass active filter.

4. Large device.
   Examples: electric powered automobile; highway bridge; aircraft; radio communication with satellite.

5. System (design or utilization of several integrated devices).
   Examples: manned mission to a planet; city water and sewer system.

In placing projects into size categories, considerations were given to complexity, sophistication, number of components, and physical size of the projects. From title alone it is not possible to accurately place projects in size categories, but with a large number of cases, some uncertainties will average out. The project size distributions for AE, EE, CE, and ME are shown in Figure 6. The flag marks on each point for AE and EE show the spread on values for evaluations by two investigators; CE and ME were evaluated by a single investigator.

The curves in Figure 6 show two distinct shapes. AE and CE projects tend to peak at size four (large device). There is a tendency to choose as student design projects the design of an entire aircraft or an entire building. The scale tends to be large. In contrast, EE and ME projects tend to peak at size two (small device). A possible explanation is that there exists an unlimited number of projects in each size category and the selection tends toward smaller projects which match better with the time available and the team size preferred (see Figure 7).

The other fields represented in this total study were not included in the plots because the total number of course titles were not sufficient for evaluation. However, trends are discernible: IE has a pattern very close to that of CE; ED is almost a duplicate of EE; E (general engineering) is almost symmetrical with a peak at size three while SE has two peaks at sizes two and four (however E and SE have 18 and 16 project titles respectively, total).

The Teaching of Engineering Design Courses

Several survey questions investigated the nature of teaching of design courses. The results are summed in Table 8, with additional details presented in Appendix I. In general, the design course includes both analysis and synthesis, has primarily a general (vs. mathematical) approach, uses

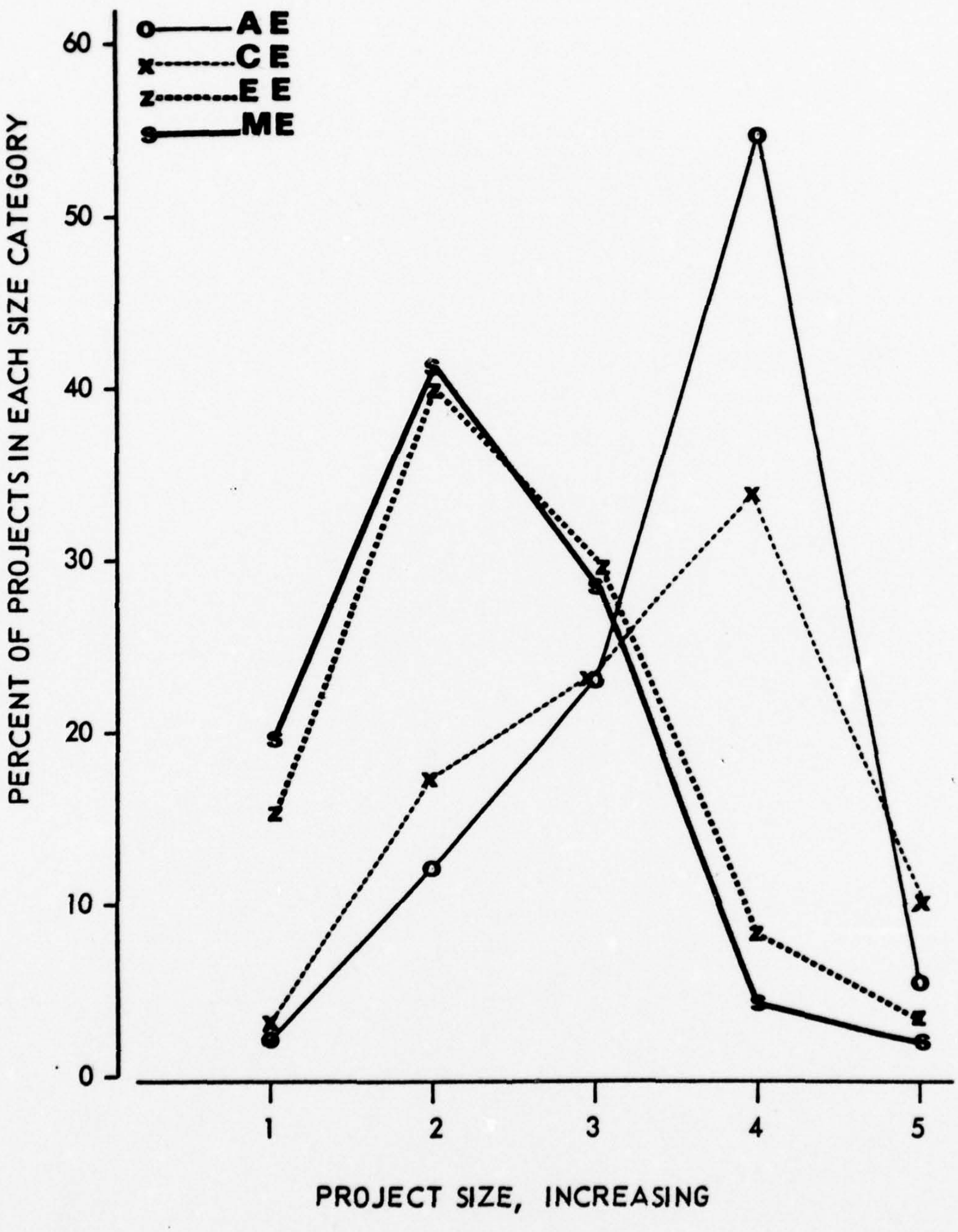


FIGURE 6. PROJECT SIZE DISTRIBUTION IN ENGINEERING DESIGN COURSES. PERCENT OF PROJECTS OF EACH SIZE. FOR DEFINITIONS OF THE SIZE CATEGORIES, SEE TEXT.

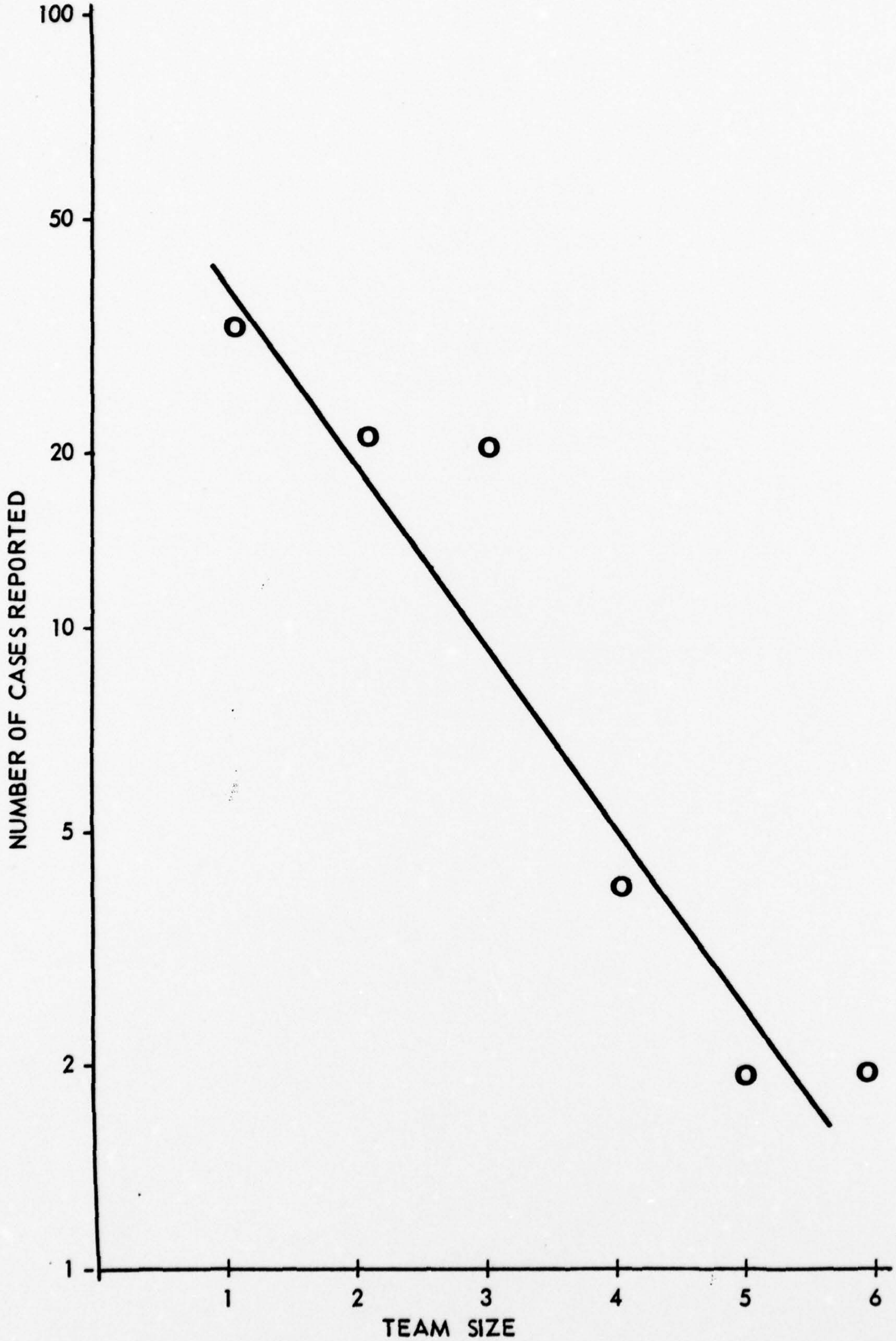


FIGURE 7. PROJECT TEAM SIZE

TABLE 8

NATURE OF TEACHING OF
ENGINEERING DESIGN COURSES

Teaching Characteristic	Per Cent Response				
	Yes	No	Both	Neither	Other
Type Design Course					
Analysis	11		60		5
Synthesis	24				
Course Approach					
General	54		23		8
Mathematical	15				
Use of Simulation and Mockups					
Simulation	7		51	35	6
Mockups	1				
Use of Case Studies	58	38			4
Use of Design Projects	79	20			1

simulation and mock-ups (59%) and/or case studies (58%), and includes one or more design projects (79%).

The category "OTHER" in regard to analysis/synthesis included blanks and responses such as: Primarily design; open-ended design approach; design methodology; basic design; and, design comes first followed by analysis.

The terms "mathematical" and "general" were not defined in the questionnaire; each respondent was free to apply his own interpretation. For a basis for future discussion we might consider a mathematical approach--one which emphasizes tools for design; the approach is quantitative and analytical. A general approach might be taken as one emphasizing the process of design; it is more likely to be qualitative and descriptive, but not necessarily so. Some respondents' comments: practical approach used; depends upon project; similar to that encountered in the practice of engineering.

While case studies were reported in 58 per cent of the courses, similar approaches appear to be taken in several courses; some respondents' comments: instructors' experiences are discussed instead; real life examples; in the form of design proposals from aerospace companies; and, not case studies, but design examples.

As reported in the section on "nature of design courses" above, a majority of the courses desire to give the student a practical experience in engineering design and an opportunity to apply the academic knowledge he has been getting. It is not surprising then that 79 per cent of the courses include one or more design projects. Appendix I gives the percentages for each field. In 96 per cent of the AE courses a project is required, and in only 63 per cent of the CE courses is one required. In up to 13 per cent of the courses, the project is the course.

On an average, about one-third of the courses have individual projects, one-third team projects, and one-third have both. Although the questionnaire did not specifically ask for team size, approximately 40 responses indicated the number of persons per team. The average team size for those specifying size center around 2-3 members per team. This is varied by the scope and complexity of the project, class size and students' interests. Figure 14 gives the results of the limited information on team size. While it is known that larger teams are used, six member teams were the largest reported in this volunteered information. Some of the AE student projects assign their student teams to various task groups (i.e. aerodynamics, structures, propulsion, etc.) which contribute to the efforts of the total project team.

Faculty influence predominates in the choosing of project subjects. Industrial Engineering is the only field where the student initiation of projects exceeds that of faculty. Another input into the selection of design project subjects was listed as coming from industry, and for some, as courses coming from the U. S. Air Force. Further details are given in Appendix I.

The Content of Engineering Design Courses

Each respondent to the survey questionnaire was asked to indicate whether each of nine selected topics was included in his course, and if included, what percentage of the course was devoted to that topic. These topics were reliability*, safety, maintainability*, operability, human resources*, creativity*, decision making, trade-off studies*, and computer aided design. The terms marked with * were defined in an attachment to the questionnaire; these definitions are reproduced in Appendix A.

Some of the respondents answered with the following topics written either in place of or in addition to the nine selected topics: optimization, aesthetics, patent law, economy, modeling, value systems, and professional method.

The results of this survey on engineering design course content are given in Figures 8, 9, 10 and 11. In these figures the topics are listed in the order given above (not the order in the questionnaire). While not precise, this ordering places topics least man-oriented at the ends, topics more man-oriented toward the center, topics having more to do with project characteristic to the left, and topics having to do with the design process to the right. The plots of coverage of these topics then provide a profile relating to the inclusion of human resources and human factors in engineering design courses for engineering design as a whole and for the separate fields of engineering.

In general, the right hand side of these plots is higher, showing that these topics are covered in more courses and in more depth. However, the differences in the totals are not great except for the greater coverage given to creativity and decision making. These are topics in which there is considerable body of knowledge with textbooks and separate courses available. There is less availability of materials concerning human resources and maintainability as applied to engineering.

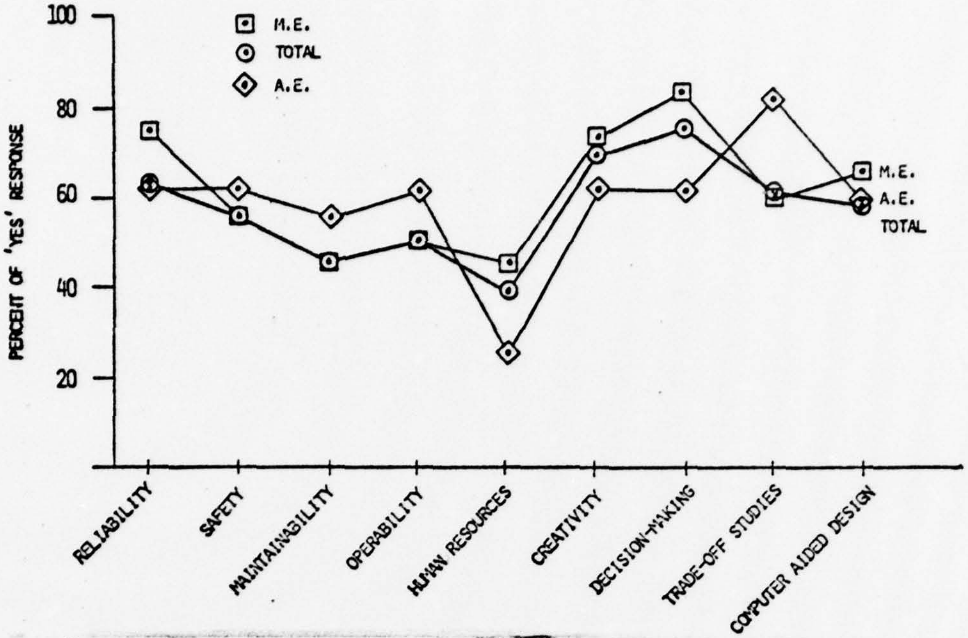
Considerable variability between fields is noted. In the number of courses including the various topics, Systems Engineering exceeds the average in eight of the nine topics while General Engineering is below average in eight of the nine. In regard to the amount of coverage given each topic (averaged over only those courses reporting a percentage), Civil Engineering exceeds the average in all nine topics, while Electrical Engineering is below average in all nine.

The data from which Figures 8, 9, 10 and 11 were constructed are given in Appendix J.

Effect of Faculty Rank

The responses by the full professors were compared to the total of the responses (including the full professors) to see if any differences or trends might be discerned.

Figure 12 shows the number of full professors responding vs. the total response for each of the eight fields queried. AE and E were high and



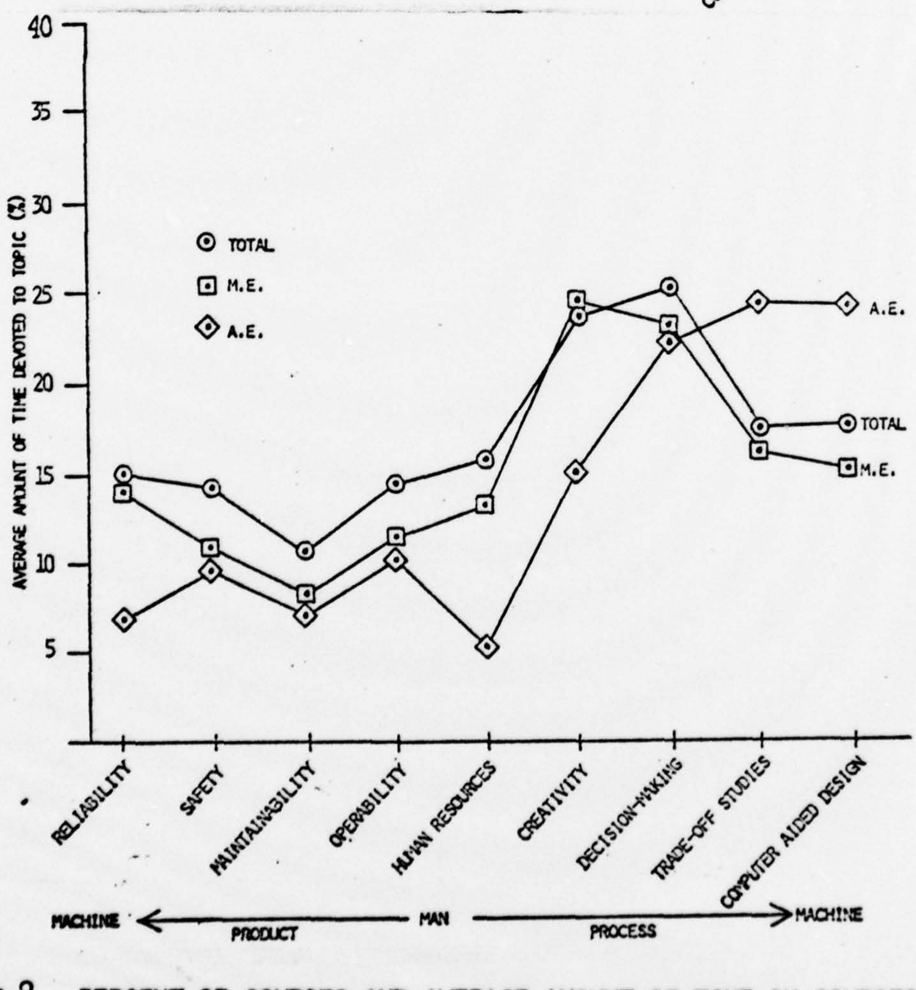


FIGURE 8. PERCENT OF COURSES AND AVERAGE AMOUNT OF TIME IN COURSES DEVOTED TO SELECTED TOPICS, FOR AEROSPACE AND MECHANICAL ENGINEERING.

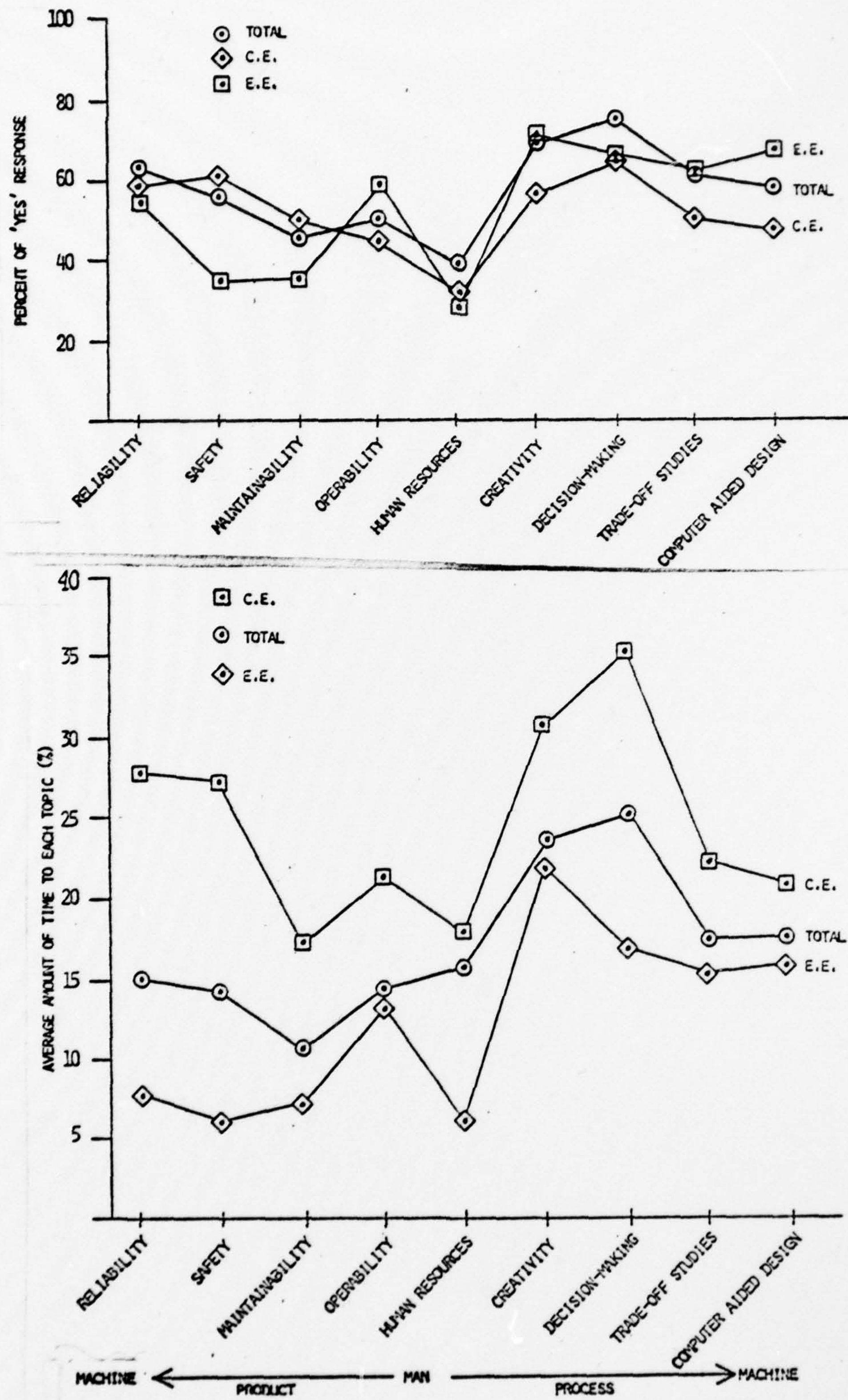


FIGURE 9. PERCENT OF COURSES COVERING AND AVERAGE AMOUNT OF TIME DEVOTED TO SELECTED TOPICS FOR ELECTRICAL AND CIVIL ENGINEERING.

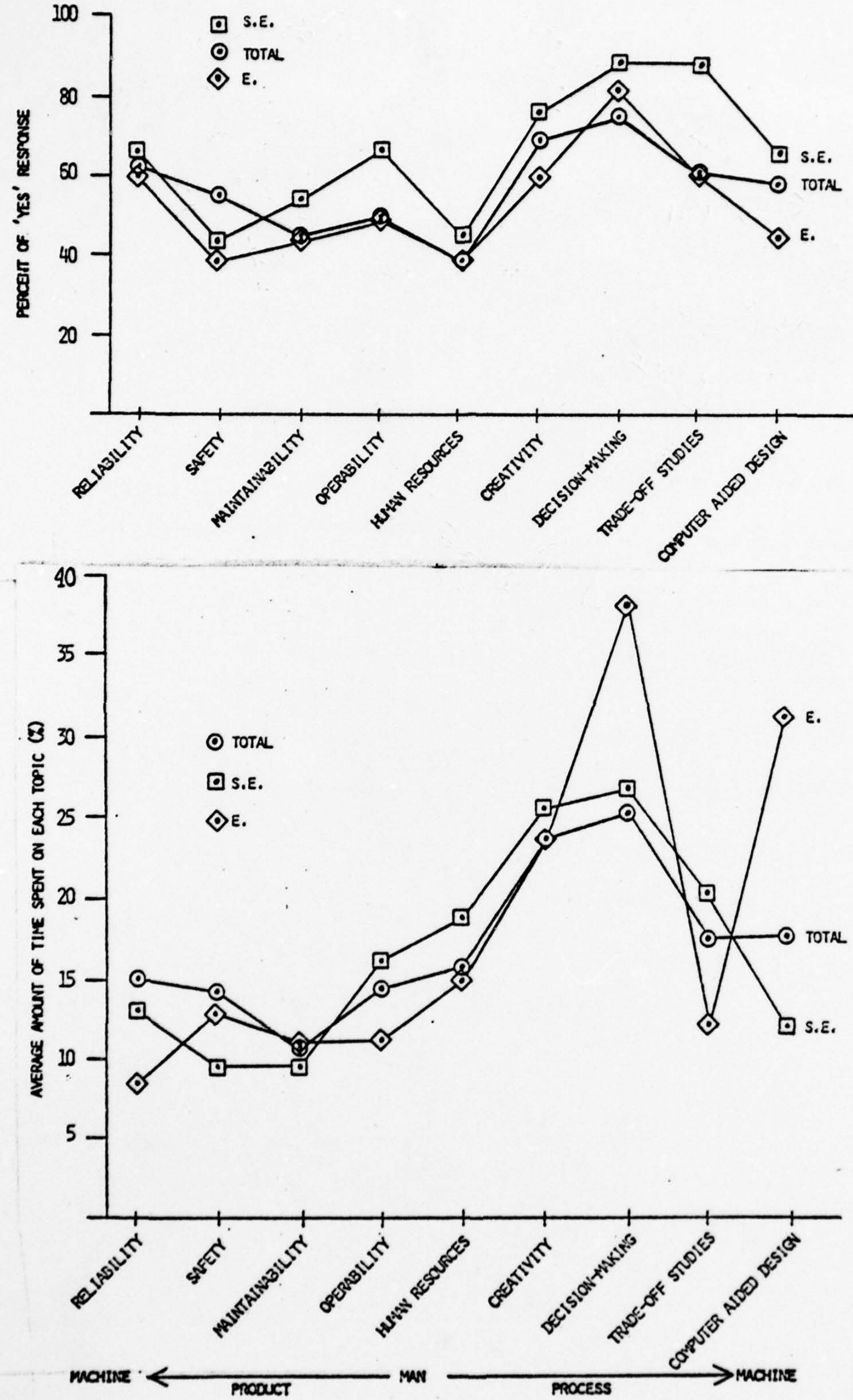


FIGURE 10. PERCENT OF DESIGN COURSES COVERING AND AVERAGE TIME DEVOTED TO SELECTED TOPICS FOR SYSTEMS ENGINEERING AND GENERAL ENGINEERING.

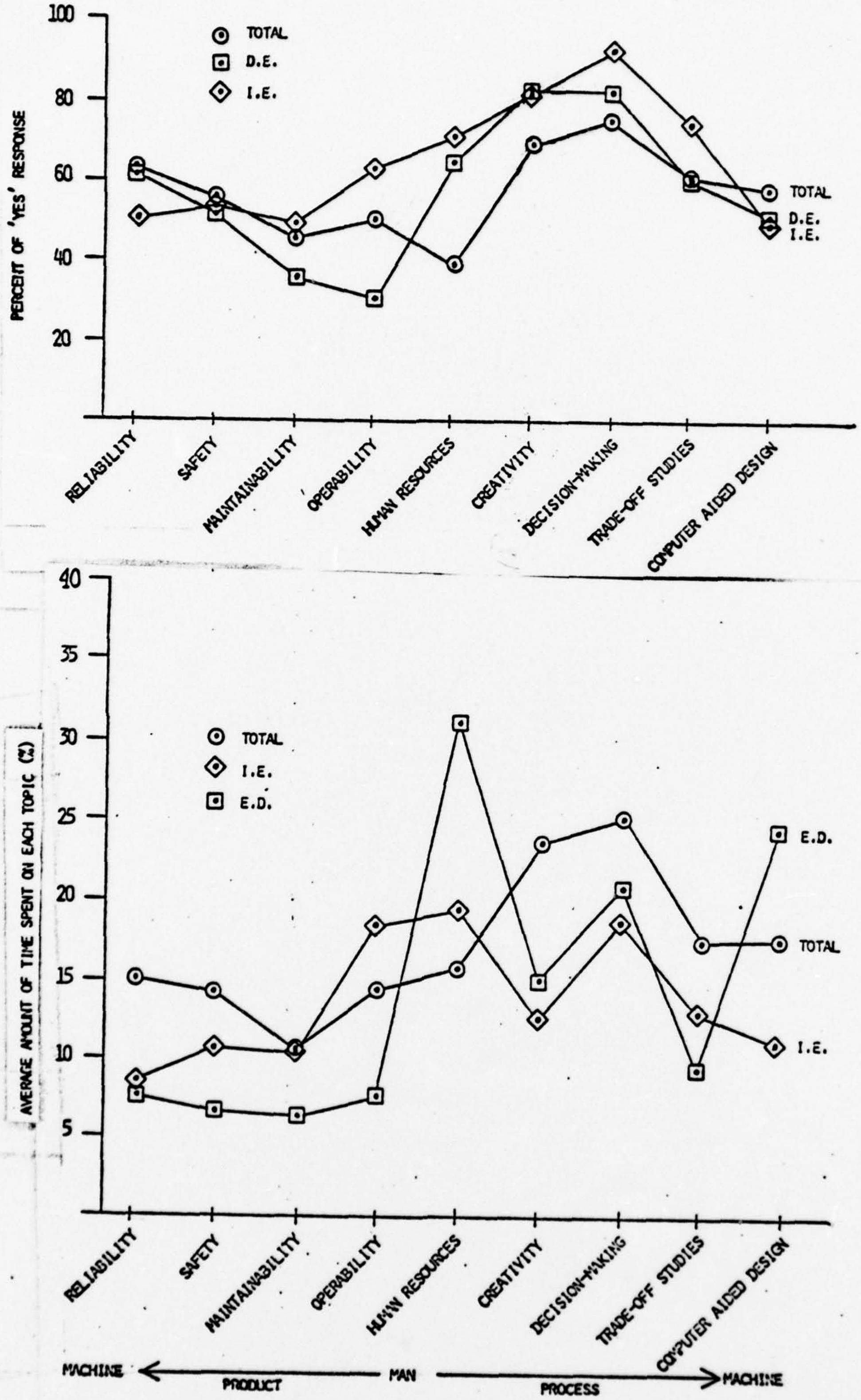


FIGURE 11. PERCENT OF DESIGN COURSES COVERING AND AVERAGE TIME DEVOTED TO SELECTED TOPICS FOR DESIGN ENGINEERING AND INDUSTRIAL ENGINEERING.

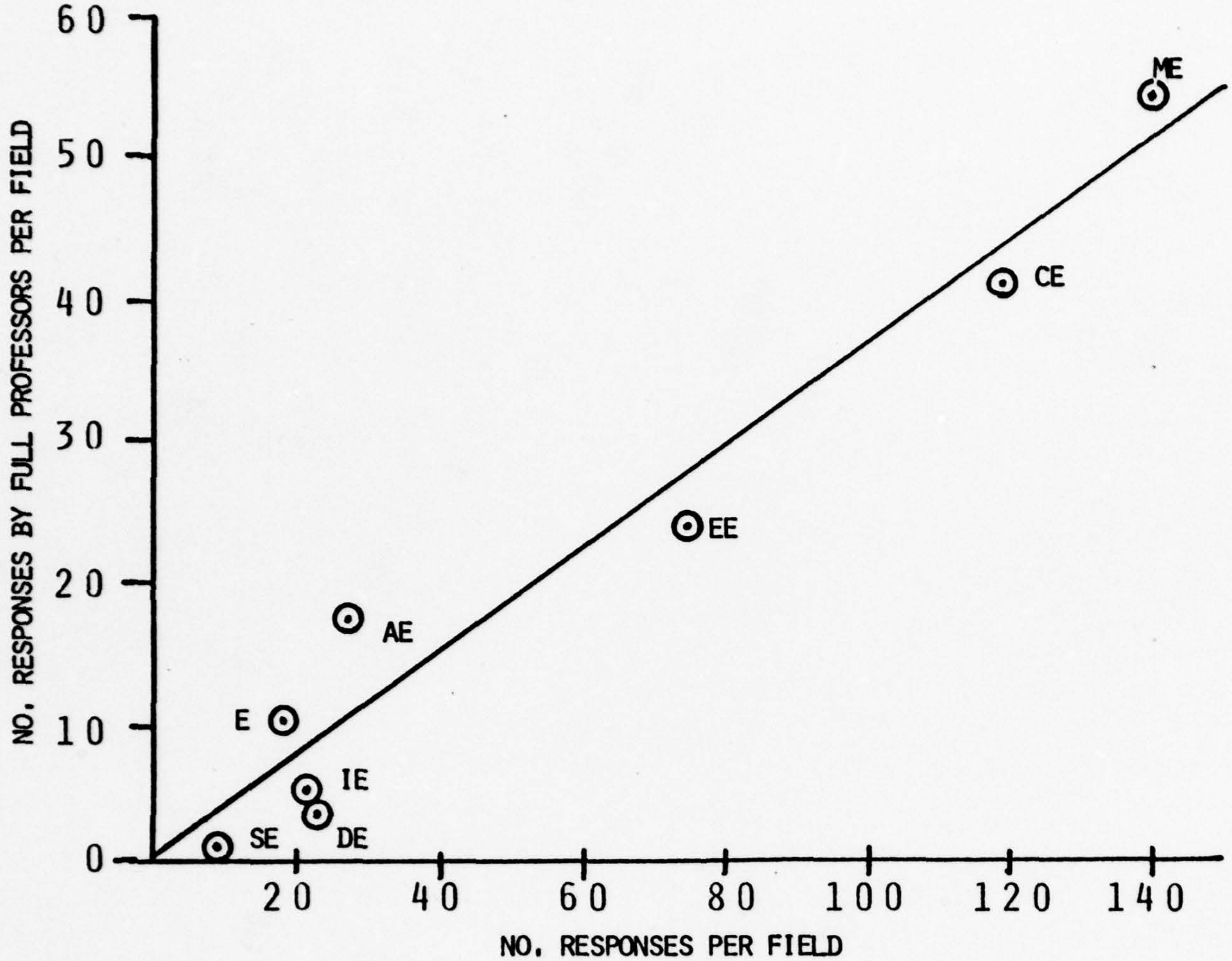


FIGURE 12. NO. OF RESPONSES BY FULL PROFESSORS BY TOTAL RESPONSE PER FIELD.

SE, IE, and DE low on responses by full professor, but the total numbers are poor for these fields. ME, CE, and EE are relatively close to the ratio of the average, 0.360, represented by the straight line shown in Figure 12.

In general, the responses by the professors were representative of the overall response:

Full Professors represent:
- 36% of all respondents,
- 35% of those specifying texts,
- 35% of those utilizing supplemental reading materials,
- 35% of those utilizing case studies,
- 37% of those incorporating design projects into their courses,
- 33% of those reporting team or team and individual projects (as contrasted to all individual projects),
- 33% of those reporting a synthesis and analysis approach, and
- 34-41% of those specifying of the objectives in Table 4 with the exception of <u>creativity</u>.

There are a few cases where the responses by the full professors were not representative of the total response. Recalling that full professors represent 36 per cent of the respondents:

1. We note that full professors represent only 15 per cent of those utilizing the "other" response to six of the questions on the survey.

2. Full professors represent 68 per cent of those reporting an analysis type course (as contrasted to a synthesis or combination analysis-synthesis type course).

3. Full professors represent 51 per cent of those reporting a mathematical approach (as contrasted to a general or combination math-general approach), and

4. Full professors represent 54 per cent of those giving <u>creativity</u> as an objective in their course.

The responses of the full professors compared to the total response showed less than 10 per cent variations in the extent to which the nine specified topics were included in design courses and in the degree of coverage given to these topics.

IV. SUMMARY AND CONCLUSIONS

In the solicitation of information on engineering design courses, many terms, including "engineering design" were used without definition. It was hoped that a definition would evolve from the replies.

One approach would be to give as a definition a summary of the results of the survey: an Engineering Design Course is a course usually given to seniors, incorporating one or more design projects 79 per cent of the time, etc. This definition is not entirely satisfactory; it could provide guidance, but at the same time allows practically anything.

Another approach is to search the answers and comments for a consensus on what characteristics place an academic course in the "design" category. This gives a definition which might prove useful in conjunction with the data in the report, in the identification of or planning of design courses. The characteristics which constitute an "engineering design course" appear to be:

1. Deals with problem(s) requiring technical and scientific input for solution.
2. "Engineering Methods" are used to attain a solution.
3. The solution results in a device or procedure.
4. Sufficient detail is developed to show that the solution is practical.
5. Instructions are developed which would permit managers, technicians, machinists, etc., to implement the solution.

Some of the characteristics of the teaching of engineering design as revealed by these studies are summarized below.

Engineering design is taught mainly at the senior level. On an average 73 per cent of the courses reported are for or open to seniors. If only undergraduate courses are considered, the courses for seniors constitute over 80 per cent of those reported.

A total of 191 different titles were specified as texts for courses being given. Most textbooks used in design courses cover the technical (science/math components) needs of the design work. Very few cover all problems of design; very few make the process of design their primary subject. The number of different texts is very large and there is no universal design text. About one-fourth of the courses do not specify a text.

From the course titles and textbook titles, it appears that many design courses have been created by including design in existing courses, e.g., approximately six kinematics and dynamics courses were listed as design. Paralleling the conclusion above concerning the nature of textbooks, it

appears that most courses emphasize the technical components of the topic of the course, with "engineering design" introduced as the procedure used by the engineer to solve the problem. Analogous to textbook characteristics, relatively few courses make the process or methodology of design their primary emphasis with particular technical problems introduced as examples and exercises.

The variety of textbooks (191 different titles) is more than matched by the variations in course titles (341 different titles). There is no universally agreed upon course or course title for engineering design education.

Most design courses (79 per cent) include one or more design projects. Civil and Aeronautical Engineering classes tend to choose large projects while Mechanical and Electrical Engineering classes choose projects of modest size.

While large projects were common in some fields, it was individual and small teams (2 or 3 students) which predominated.

A majority of the courses state as an objective the providing of an opportunity to apply knowledge gained in other courses. Slightly less than a majority desired to give the students a practical, real-world experience in design. Creativity, learning to work in groups, and improving communicating ability were each given as an objective in approximately 10 per cent of the courses.

Eighty four per cent of the courses were reported as being of a synthesis type or a combination analysis/synthesis. Fifty four per cent reported a general approach while another 23 per cent reported a combination of general and mathematical.

Fifty nine per cent reported using simulation and/or mockups while 35 per cent used neither. Fifty eight per cent of the courses utilized case studies.

Human Resources Variables in Engineering Design Education

Human resources data and human factors engineering have not made a large impact in engineering education. Of nine topics relating to these areas, decision-making is included in 76 per cent of the courses, with an average of 25 per cent coverage in the courses including it. At the other end of the scale, human resources is included in 39 per cent of the courses with 16 per cent coverage in these courses.

The topics which have been established as scholarly areas for study, with textbooks and courses available, are the ones receiving the more complete coverage. Creativity and decision-making rated high, reliability and computer aided design intermediate, and human resources and maintainability received low ratings as to coverage in design courses.

Only three of 191 textbooks pertained directly to human factors; the number of texts containing a chapter or more on human factors is also very small.

From the survey questions requesting the course description and objectives and philosophies, the following percentages indicate the number of courses including human factors or human resources key words (safety, human, man-machine, maintainability, ergonomics): ME - 12%; EE - 4%; AE - 7%; CE - 3%; E - 0%; SE - 11%; ED - 26% and IE - 23%. The predominant keyword was "safety" with the areas of "maintainability" and "maintenance requirements" being mentioned only twice.

Relative Adequacy of Engineering Design Courses

In an earlier section of this report the number of design courses reported was compared to the number of departments in each of the fields (see Figure 2). This result showed an approximately linear relation except for Civil Engineering, which had a relatively large number of design courses.

When the number of design courses per field is plotted against the number of graduates in that field, Civil Engineering now moves into line while Electrical Engineering moves out, appearing to have a quite low number of design courses. This relation is shown in Figure 13.

Figure 14 shows a relation between the design courses per student and the supply of students. This curve makes an assumption which is somewhat implicit in much of this report, that the fraction of units reporting is approximately constant across fields. The number of students per job opening is based on student enrollment in a single year (Fall, 1973) while the projected average demand is for the 1974-1984 decade. Accepting these data combinations and assumptions, the results appear interesting; they say that the areas with greatest number of engineering design courses per student are the areas where employment prospects are best.

Suggested Approaches to Engineering Design Education

The project approach to engineering design appears to be a good approach. It is used by 79 per cent of the courses. The point might be asked, what is the optimum project size for a design class? A large project engenders enthusiasm. It provides motivation. It may also lead to dissatisfaction when the new engineer finds himself assigned to smaller scale work in his first job assignment. What are typical assignments given to new engineers? What are the anticipations of the employers? of the new engineers? What is the optimum approach in a design course? These are questions which might warrant further study.

A possible design education approach might be a two step process:

1. The students perform a conceptual phase design for a large scale project (motivating; provides a broad perspective of the field).
2. The students, individually or in small teams, do the detailed design work for various parts of a large project, the initial overall design having been done by the faculty. This must <u>not</u> be the design done in step 1. (This approach provides a

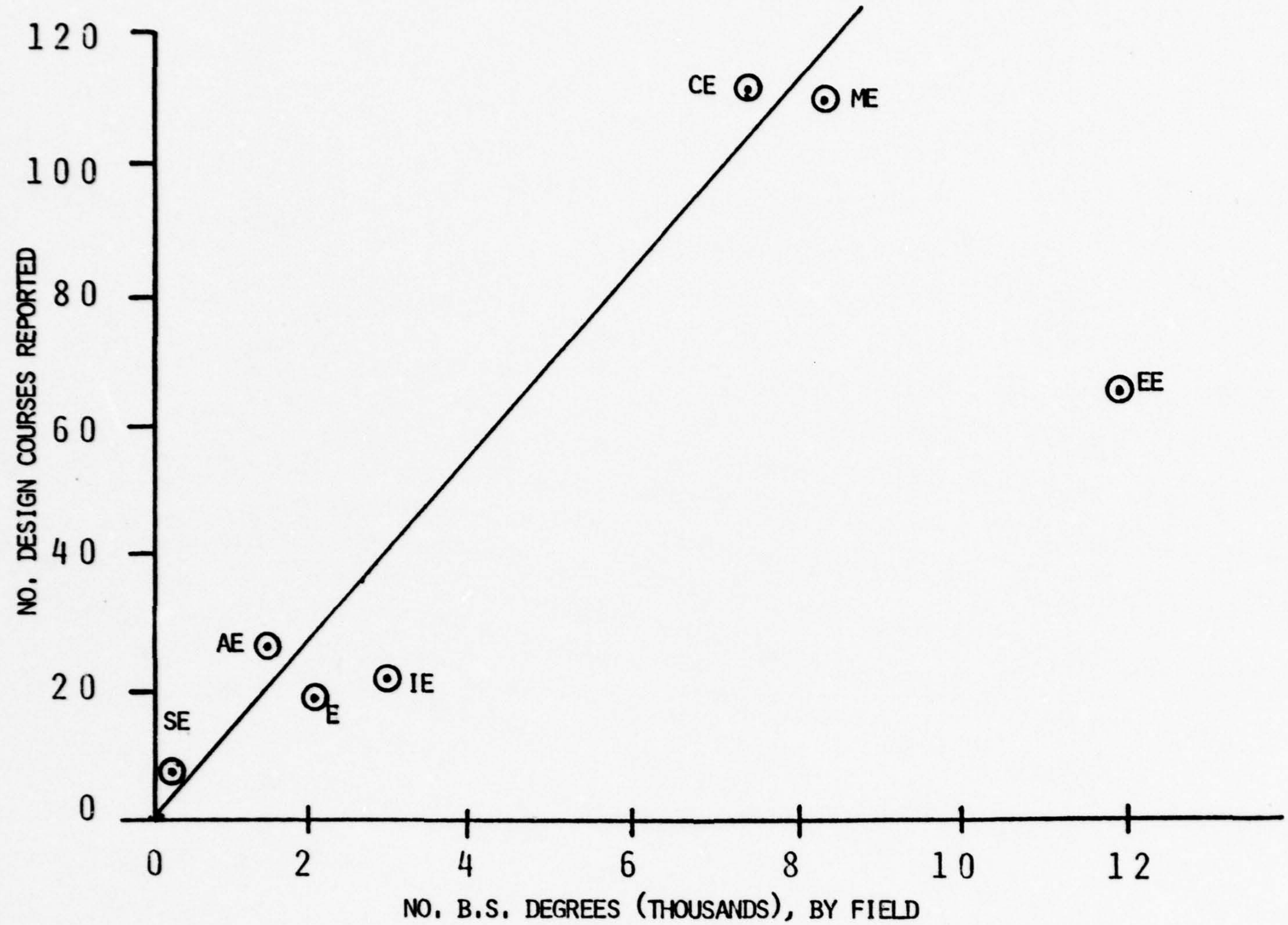


FIGURE 13. NO. DESIGN COURSES REPORTED VS. NO. B.S. DEGREES AWARDED, BY FIELD - UNITED STATES*

*ENGINEERING AND TECHNOLOGY GRADUATES, 1973, ENGINEERING MANPOWER COMMISSION REPORT

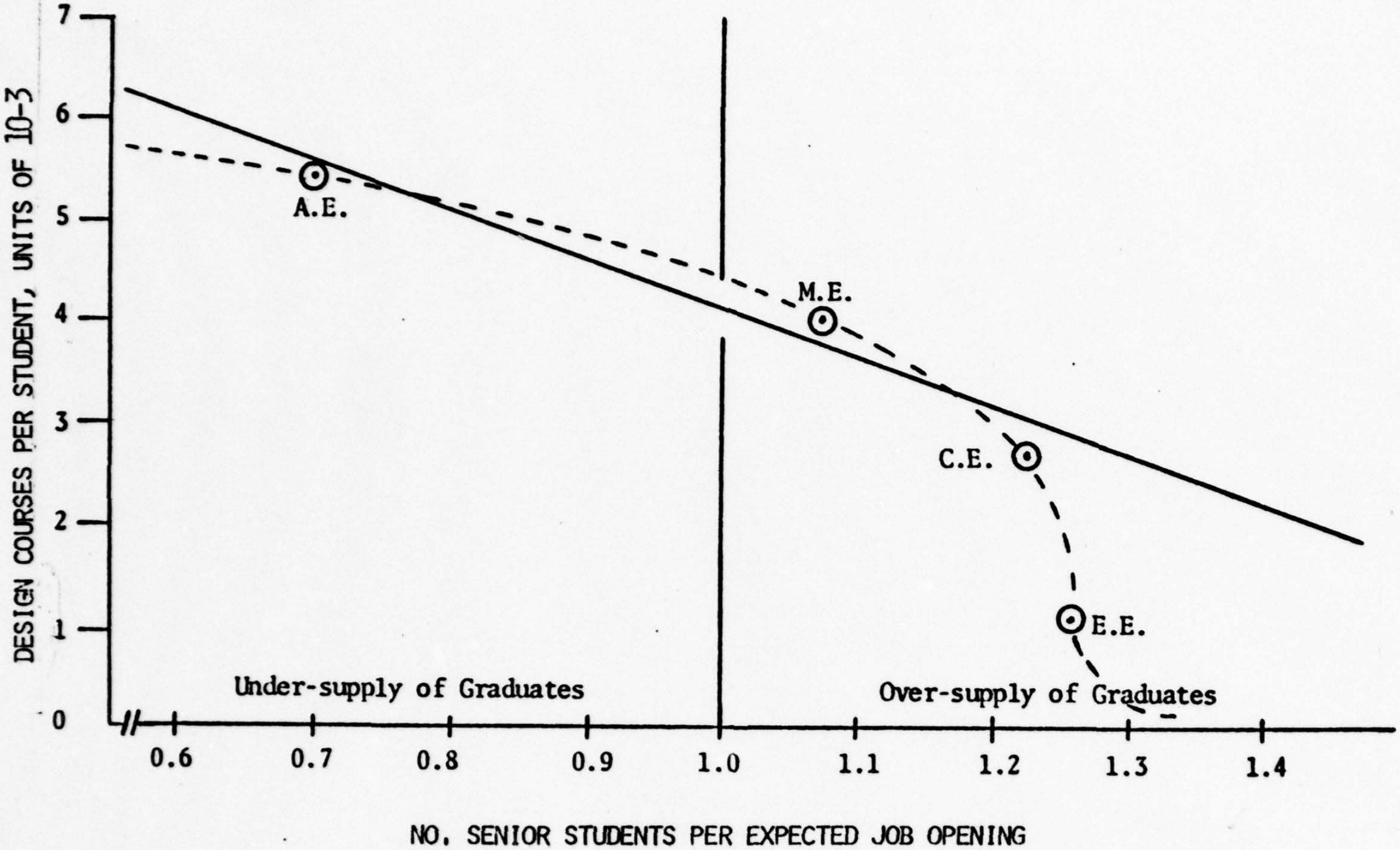


FIGURE 14. RELATION OF NUMBER OF DESIGN COURSES TO JOB MARKET FOR ENGINEERING STUDENTS OPENINGS ARE AVERAGE 1974-1984, ENGINEERING MANPOWER COMMISSION ESTIMATES.

realistic experience and shapes their job anticipations while maintaining the enthusiasm of a large scale project.)

The incompleteness of coverage of human resource variables in textbooks and in engineering design courses suggests this as an area for making improvements. Making human resources and human factors data more available via handbooks and textbooks would be a step toward increasing engineering awareness and capability concerning these factors. Making faculty more aware and confident in these areas via conferences, institutes and short courses would increase the probability of transferring the knowledge and concern to the student. Finally, the design engineer must be made to feel that human resource variables and human factors are important to his work; there must be a pay-off to the engineer, an incentive for him to utilize these factors in his design work.

To the extent that human factors and human resource data can enter the design process, the process and the product will be improved.

REFERENCES

Statistical Abstract of the United States, 92nd Annual Edition, U. S. Department of Commerce, 1971.

American Society of Engineering Education, Supplement to November 1973, Vol. 64, No. 2, p. 53.

APPENDIX A

The Questionnaire

APPENDIX A-1

Wright State University Dayton, Ohio 45431 513 426 6650

Department of Engineering

September 1974

SUBJECT: Engineering Design Education Project

Dear Chairman:

We are conducting a survey of all the Engineering Design Courses taught in a selected sample of schools across the country and would very much appreciate your helping us in this regard. Please fill in the attached questionnaire, one for each engineering design course offered in your department. A self-addressed postpaid envelope is also enclosed for the return of the questionnaire. We will make the results of this available to you, if requested.

Thank you for your time and the consideration shown to this above request.

Yours sincerely,

S. Nataraj

S. Nataraj

John M. Howard

John M. Howard

Enc: 3 sets of Questionnaire
1 Envelope

SN/JMH-dch

APPENDIX A-2

ENGINEERING DESIGN EDUCATION PROJECT

QUESTIONNAIRE

1. Name:

2. Position:

3. Department:

4. College and/or University:

5. Specific Engineering Design Course:

6. Education level at which this course is taught:

7. Prerequisites or background expected of the students for this course:

8. Course Description:

9. Textbook(s) used for this course:

10. Supplementary reading materials (such as trade magazines and scientific journals) used for this course:

11. Objectives and philosophies of this course:

12. Is this design course of an analysis type or synthesis type:

13. Is this course taught mainly with a mathematical approach or with a general approach?

14. Are any of the following topics* covered in this design course? If so, to what extent?

a)	Reliability	No ______;	Yes ______;	______%
b)	Maintainability	No ______;	Yes ______;	______%
c)	Decision-making	No ______;	Yes ______;	______%
d)	Computer Aided Design	No ______;	Yes ______;	______%
e)	Creativity	No ______;	Yes ______;	______%
f)	Human Resources	No ______;	Yes ______;	______%
g)	Trade-off studies	No ______;	Yes ______;	______%
h)	Safety	No ______;	Yes ______;	______%
i)	Operability	No ______;	Yes ______;	______%

15. Are case studies utilized in this course?

16. Is there a design project to go with this course?

17. Is this project conducted on an individual or a team approach?

18. Do these projects involve the use of simulation and/or mock-ups?

19. Are these projects faculty initiated or student initiated?

20. Would you like to receive a copy of the results of this project?
______ Yes ______ No

OPTIONAL

21. Please list some project titles.

22. If available, would you please send us a sample student project?

* The definitions of some of the terms are given on the attached sheet.

APPENDIX A-4

DEFINITIONS*

Reliability: is the probability that the system will perform satisfactorily for a given period of time when used under stated conditions.

Maintainability: is a quality of the combined features and characteristics of a design which may be expressed as the probability that within a given period of time an item can be made to conform to specifications when maintenance action is performed by personnel of average or available skills in accordance with prescribed procedures and resources.

Creativity: is a successful step across the borderline of knowledge. This is often considered to be a personal trait whereby an individual by means of association, intuition, hard work or other means comes up with a successful solution to a difficult problem, a solution that is not obvious to the average designer.

Human Resources: includes those data that describes the kind, proficiency and quantity of human skills which is expected to be requieed to operate or service the device, project or system being designed; can also include data that describes the cost, time and feasibility of producing the skills that are anticipated to be needed if these are not ordinarily available.

Trade-Off studies: is a thoughtful balance between first cost, function, appearance, convenience, maintainability, safety and life required in differing degrees depending upon the assumed priorities to achieve an optimum or the best value for a given situation.

Repairability: is the probability that when maintenance action due to equipment failure is taken, the system will be restored to a satisfactory operating condition in a given period of time.

APPENDIX B

Geographic Distribution of Questionnaires Returned

APPENDIX B

STATE LISTING BY REGION*

Number of Questionnaires Received from Each State and Region

1. New England

Maine	(3)
New Hampshire	(2)
Vermont	(2)
Massachusetts	(35)
Rhode Island	(2)
Connecticut	(6)
Total	(50)

2. Middle Atlantic

New York	(17)
New Jersey	(8)
Pennsylvania	(7)
Total	(32)

3. East-South Central

Kentucky	(11)
Tennessee	(3)
Alabama	(3)
Mississippi	(5)
Total	(22)

4. East-North Central

Ohio	(25)
Indiana	(13)
Illinois	(7)
Michigan	(27)
Wisconsin	(3)
Total	(75)

5. South Atlantic

Delaware	(1)
Maryland	(3)
District of Columbia	(0)
Virginia	(21)
West Virginia	(1)
North Carolina	(5)
South Carolina	(3)
Georgia	(2)
Florida	(5)
Total	(41)

6. West-North Central

Minnesota	(0)
Iowa	(6)
Missouri	(3)
North Dakota	(1)
South Dakota	(11)
Nebraska	(1)
Kansas	(12)
Total	(34)

7. West-South Central

Arkansas	(0)
Louisiana	(1)
Oklahoma	(8)
Texas	(18)
Total	(27)

8. Pacific

Washington	(10)
Oregon	(8)
California	(38)
Alaska	(0)
Hawaii	(1)
Total	(57)

9. Mountain

Montana	(1)
Idaho	(1)
Wyoming	(1)
Colorado	(0)
New Mexico	(3)
Arizona	(5)
Utah	(5)
Nevada	(1)
Total	(17)

10. Non-United States

Canada	(49)
Puerto Rico	(3)
Total	(52)

*Statistical Abstract of the United States 1971

APPENDIX C

Engineering Fields and Geographic Distribution

APPENDIX C

ENGINEERING FIELD LISTING BY REGION*

Number of Questionnaires Received from Each Engineering Field

1. New England

M.E.	(15)
E.E.	(2)
A.E.	(2)
C.E.	(5)
E.	(4)
S.E.	(0)
E.D.	(21)
I.E.	(1)
Ch.E.	(0)

2. Middle Atlantic

M.E.	(7)
E.E.	(5)
A.E.	(1)
C.E.	(13)
E.	(2)
S.E.	(0)
E.D.	(0)
I.E.	(4)
Ch.E.	(0)

3. East-South Central

M.E.	(10)
E.E.	(7)
A.E.	(1)
C.E.	(4)
E.	(0)
S.E.	(0)
E.D.	(0)
I.E.	(0)
Ch.E.	(0)

4. East-North Central

M.E.	(19)
E.E.	(18)
A.E.	(6)
C.E.	(16)
E.	(3)
S.E.	(3)
E.D.	(0)
I.E.	(9)
Ch.E.	(1)

5. South Atlantic

M.E.	(7)
E.E.	(3)
A.E.	(7)
C.E.	(17)
E.	(4)
S.E.	(3)
E.D.	(0)
I.E.	(0)
Ch.E.	(0)

6. West-North Central

M.E.	(5)
E.E.	(6)
A.E.	(5)
C.E.	(18)
E.	(0)
S.E.	(0)
E.D.	(0)
I.E.	(0)
Ch.E.	(0)

7. West-South Central

M.E.	(11)
E.E.	(8)
A.E.	(1)
C.E.	(4)
E.	(0)
S.E.	(0)
E.D.	(0)
I.E.	(3)
Ch.E.	(0)

8. Pacific

M.E.	(21)
E.E.	(9)
A.E.	(4)
C.E.	(14)
E.	(4)
S.E.	(2)
E.D.	(0)
I.E.	(3)
Ch.E.	(0)

9. Mountain

M.E.	(9)
E.E.	(4)
A.E.	(0)
C.E.	(3)
E.	(0)
S.E.	(0)
E.D.	(0)
I.E.	(1)
Ch.E.	(0)

10. Non-United States

M.E.	(30)
E.E.	(8)
A.E.	(0)
C.E.	(8)
E.	(0)
S.E.	(1)
E.D.	(2)
I.E.	(1)
Ch.E.	(2)

*Statistical Abstract of the United States 1971

APPENDIX D

Returned Questionnaires by ASEE Sections

APPENDIX D

STATE LISTING BY ASEE SECTION

Number of Questionnaires Received from Each State and Section

1. New England

Maine	(3)
New Hampshire	(2)
Massachusetts	(35)
Vermont	(2)
Rhode Island	(2)
Connecticut	(6)
Total	(50)

2. Middle Atlantic

Delaware	(2)
Maryland	(3)
Central and Eastern Pennsylvania	(5)
New Jersey	(9)
New York City and Long Island	(4)
District of Columbia	(0)
Total	(23)

3. North Central

Ohio	(26)
West Virginia	(1)
Western Pennsylvania	(2)
Michigan	(27)
Total	(56)

4. Southeastern

Virginia	(21)
North Carolina	(5)
South Carolina	(3)
Kentucky	(11)
Tennessee	(3)
Mississippi	(5)
Alabama	(3)
Georgia	(2)
Florida	(5)
Puerto Rico	(3)
Total	(61)

5. Midwest

Arkansas	(0)
Oklahoma	(8)
Missouri	(5)
Kansas	(12)
Nebraska	(1)
Total	(26)

6. North Midwest

Manitoba	(5)
Ontario	(14)
North Dakota	(1)
Eastern/South Dakota	(10)
Minnesota	(0)
Iowa	(6)
Wisconsin	(3)
Total	(39)

7. Indiana/Illinois

Indiana	(12)
Illinois	(5)
Total	(17)

8. Gulf-Southwest

Texas	(18)
Louisiana	(1)
New Mexico	(3)
Total	(22)

9. Pacific Southwest

Nevada	(1)
California	(39)
Arizona	(5)
Hawaii	(1)
Total	(46)

10. Pacific Northwest

Oregon	(8)
Idaho	(1)
Washington	(9)
Montana	(1)
British Columbia	(7)
Alberta	(6)
Saskatchewan	(2)
Alaska	(0)
Total	(34)

11. Rocky Mountain

Utah	(5)
Colorado	(0)
Wyoming	(1)
Western/South Dakota	(1)
Total	(7)

12. St. Lawrence

Quebec	(11)
New York	(11)
Nova Scotia	(1)
New Brunswick	(3)
Total	(26)

APPENDIX E

Engineering Fields and ASEE Sections

APPENDIX E

ENGINEERING FIELD LISTING BY ASEE SECTION

Number of Questionnaires Received from Each Engineering Field

1. New England

M.E.	(15)
E.E.	(2)
A.E.	(2)
C.E.	(5)
E.	(4)
S.E.	(0)
E.D.	(21)
I.E.	(1)
Ch.E.	(0)

2. Middle Atlantic

M.E.	(5)
E.E.	(3)
A.E.	(3)
C.E.	(7)
E.	(1)
S.E.	(0)
E.D.	(0)
I.E.	(4)
Ch.E.	(0)

3. North Central

M.E.	(13)
E.E.	(19)
A.E.	(4)
C.E.	(14)
E.	(1)
S.E.	(3)
E.D.	(0)
I.E.	(1)
Ch.E.	(1)

4. Southeastern

M.E.	(19)
E.E.	(10)
A.E.	(4)
C.E.	(21)
E.	(4)
S.E.	(3)
E.D.	(0)
I.E.	(0)
Ch.E.	(0)

5. Midwest

M.E.	(7)
E.E.	(6)
A.E.	(1)
C.E.	(12)
E.	(0)
S.E.	(0)
E.D.	(0)
I.E.	(0)
Ch.E.	(0)

6. North Midwest

M.E.	(9)
E.E.	(5)
A.E.	(5)
C.E.	(13)
E.	(0)
S.E.	(1)
E.D.	(2)
I.E.	(3)
Ch.E.	(1)

7. Indiana/Illinois

M.E.	(6)
E.E.	(1)
A.E.	(3)
C.E.	(0)
E.	(2)
S.E.	(0)
E.D.	(0)
I.E.	(5)
Ch.E.	(0)

8. Gulf-Southwest

M.E.	(10)
E.E.	(7)
A.E.	(0)
C.E.	(2)
E.	(0)
S.E.	(0)
E.D.	(0)
I.E.	(3)
Ch.E.	(0)

9. Pacific Southwest

M.E.	(16)
E.E.	(13)
A.E.	(3)
C.E.	(8)
E.	(4)
S.E.	(2)
E.D.	(0)
I.E.	(0)
Ch.E.	(0)

10. Pacific Northwest

M.E.	(15)
E.E.	(1)
A.E.	(1)
C.E.	(14)
E.	(0)
S.E.	(0)
E.D.	(0)
I.E.	(3)
Ch.E.	(0)

11. Rocky Mountain

M.E.	(6)
E.E.	(0)
A.E.	(0)
C.E.	(0)
E.	(0)
S.E.	(0)
E.D.	(0)
I.E.	(1)
Ch.E.	(0)

12. St. Lawrence

M.E.	(13)
E.E.	(3)
A.E.	(1)
C.E.	(6)
E.	(1)
S.E.	(0)
E.D.	(0)
I.E.	(1)
Ch.E.	(1)

APPENDIX F

Engineering Design Textbooks

APPENDIX F-1

ENGINEERING DESIGN TEXTBOOKS

1. Asimow, Morris, Introduction to Design, Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 1962.

2. Beakley, George C., and Ernest G. Chilton, Introduction to Engineering Design and Graphics, The Macmillan Company, New York, 1973.

3. Brichta, A. M. and Peter M. Sharp, From Project to Production, Pergamon Press, London, 1970.

4. Chestnut, H., System Engineering Tools, John Wiley and Sons, New York, 1965.

5. Chestnut, H., System Engineering Methods, John Wiley and Sons, New York, 1967.

6. Eckman, Donald P. (ed.), Systems: Research and Design, John Wiley and Sons, Inc., New York, 1961.

7. Gague, R. M. (ed.), Psychological Principles in System Development, Holt, Rinehart and Winston, New York, 1962.

8. Geise, John and Walker W. Hooler, Maintainability Engineering, U. S. Army Material Command and Martin Company, Orlando Division, 1965.

9. Goode, Harry H., and Robert E. Machol, System Engineering: An Introduction to the Design of Large-Scale Systems, New York, McGraw-Hill, 1957.

10. Gregg, Gordon L., The Design of Design, The University Press, Cambridge, 1969.

11. Gregory, S. A. (ed.), The Design Method, Plenum Press, New York, 1966.

12. Hall, Arthur D., A Methodology for Systems Engineering, D. Van Nostrand Company, Inc., Princeton, N. J., 1962.

13. Harrisberger, Lee, Engineersmanship, A Philosophy of Design, Brooks/Cole Publishing Company, Belmont, California, a division of Wadsworth Publishing Company, Inc., 1966.

14. Hill, Percy H., The Science of Engineering Design, Holt, Rinehart and Winston, Inc., New York, 1970.

15. Jones, J. Christopher, Design Methods - Seeds of Human Futures, Wiley-Interscience, a division of John Wiley and Sons, New York, 1970.

16. Krick, E. V., An Introduction to Engineering and Engineering Design, John Wiley and Sons, Inc., New York, 1969.

APPENDIX F-2

17. Meredith, Dale D., et.al, Design and Planning of Engineering Systems, Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 1973.

18. Middendorf, William H., Engineering Design, Allyn and Bacon, Inc., Boston, 1969.

19. Pare, Eugene, et.al, Introduction to Engineering Design, Holt, Rinehart and Winston, New York, 1963.

20. Tribus, Myron, Rational Descriptions, Decisions and Designs, Pergamon Press, New York, 1969.

21. Wilson, Iva G., Information, Computers, and System Design, John Wiley and Sons, Inc., New York, 1965.

22. Wilson, Warren E., Concepts of Engineering System Design, McGraw-Hill, New York, 1965.

APPENDIX G

Textbook Usage Reported by Engineering Design Education Survey

APPENDIX G

TEXTBOOK USAGE REPORTED BY ENGINEERING DESIGN EDUCATION SURVEY

	M.E.	E.E.	C.E.	A.E.	I.E.	E.D.	E.	S.E.	TOTAL
PER CENT OF DESIGN COURSES									
SPECIFYING TEXT	78	65	82	48	86	71	67	67	74
NOT SPECIFYING TEXT	22	35	18	52	14	29	33	33	26
SPECIFYING MORE THAN ONE TEXT	12	6	15	15	9	10	6	17	12
NO. TEXTS PERTAINING TO HUMAN FACTORS	0	0	0	0	3	0	0	0	3
TOTAL DIFFERENT TEXTS LISTED	46	41	50	8	16	11	12	7	191
NO. TEXTS SPECIFIED MORE THAN ONCE	18	7	19	2	2	0	0	0	48
MOST FREQUENTLY LISTED TEXT (NO. TIMES LISTED) (SEE TITLES BELOW)	(26)	(3)	(13)	(3)	(3)	-	-	-	-
NO. DESIGN COURSES REPORTED (FROM TABLE 2)	140	75	119	27	22	23	18	9	433

Note: First three rows include textbooks, manuals, handbooks, etc.; remainder of table includes only textbooks.

MOST FREQUENTLY USED TEXTS

M.E. - Mechanical Engineering Design, Shigley (26)
E.E. - Network Analysis and Synthesis, Kuo (3)
C.E. - Design of Concrete Structures, Winter & Nilson (13)
A.E. - Supersonic and Subsonic Airplane Design, Corning (3)
I.E. - Plant Layout, Reed (3)
E.D. - None specified more than once
E. - None specified more than once
S.E. - None specified more than once

APPENDIX H

Course Titles: Engineering Design Courses

APPENDIX H

COURSE TITLES: ENGINEERING DESIGN COURSES

	M.E.	E.E.	A.E.	C.E.	E.	S.E.	E.D.	I.E.	TOTAL*
TOTAL NUMBER OF COURSE TITLES	134	65	27	119	18	9	23	22	417
DIFFERENT TITLES									
NUMBER	87	58	26	98	18	9	23	21	340
PER CENT	65%	89%	96%	82%	100%	100%	100%	95%	82%
TOTAL NUMBER OF COURSE TITLES INCORPORATING THE WORD "DESIGN"	119	40	25	77	13	4	16	14	308
DIFFERENT TITLES INCORPORATING "DESIGN"									
NUMBER	72	33	21	56	13	4	15	13	227
PER CENT	61%	83%	84%	73%	100%	100%	94%	93%	74%
$\frac{\text{TOTAL "DESIGN"}}{\text{TOTAL TITLES}}$ %	89%	62%	93%	65%	72%	44%	70%	64%	74%
TOTAL COURSE TITLES INCORPORATING THE WORD "LABORATORY"									
NUMBER	1	6	0	0	0	2	0	0	9
PER CENT	1%	9%	-	-	-	22%	-	-	2%

*Duplication, if any, between fields not totally eliminated. Duplication was very small; total titles do not equal total courses as 16 courses did not list a title.

APPENDIX I

The Nature of Teaching of Design Courses

APPENDIX I-1

PERCENTAGE DISTRIBUTION OF ANALYSIS OR SYNTHESIS
TYPE ENGINEERING DESIGN COURSES BY ENGINEERING FIELD

	M.E.	E.E.	A.E.	C.E.	E.	S.E.	E.D.	I.E.	TOTAL
ANALYSIS	16%	4%	11%	10%	5%	-	4%	18%	11%
SYNTHESIS	22%	31%	37%	17%	34%	11%	26%	18%	24%
BOTH	58%	63%	52%	63%	50%	78%	66%	64%	60%
OTHER	4%	2%	-	10%	11%	11%	4%	-	5%

APPENDIX I-2

PERCENTAGE DISTRIBUTION OF MAINLY MATHEMATICAL OR GENERAL APPROACH TO THE WAY THE COURSE IS TAUGHT BY ENGINEERING FIELD

	M.E.	E.E.	A.E.	C.E.	E.	S.E.	E.D.	I.E.	TOTAL
GENERAL	51%	54%	59%	64%	50%	11%	57%	77%	54%
MATHEMATICAL	23%	13%	8%	7%	33%	22%	17%	-	15%
BOTH	18%	20%	33%	29%	11%	67%	17%	18%	23%
OTHER	8%	10%	-	10%	6%	-	9%	5%	8%

APPENDIX I-3

PERCENTAGE DISTRIBUTION OF USE OF SIMULATION AND/OR MOCK-UPS FOR COURSES WITH DESIGN PROJECTS BY ENGINEERING FIELD

	M.E.	E.E.	A.E.	C.E.	E.	S.E.	E.D.	I.E.	TOTAL
SIMULATION	4%	3%	8%	11%	-	12%	10%	10%	7%
MOCK-UPS	-	-	8%	2%	-	-	-	-	1%
BOTH	59%	67%	30%	17%	81%	38%	80%	65%	51%
NO	35%	18%	54%	59%	19%	38%	10%	15%	35%
OTHER	2%	12%	-	11%	-	12%	-	10%	6%

APPENDIX I-4

PERCENTAGE DISTRIBUTION OF COURSES UTILIZING CASE STUDIES BY ENGINEERING FIELD

	M.E.	E.E.	A.E.	C.E.	E.	S.E.	E.D.	I.E.	TOTAL
YES	54%	47%	44%	67%	61%	78%	78%	50%	58%
NO	41%	45%	56%	30%	33%	22%	13%	50%	38%
OTHER	5%	8%	-	3%	6%	-	9%	-	4%

APPENDIX I-5

PERCENTAGE DISTRIBUTION OF COURSES WITH A DESIGN PROJECT BY ENGINEERING FIELD

	M.E.	E.E.	A.E.	C.E.	E.	S.E.	E.D.	I.E.	TOTAL
YES	81%	88%	96%	63%	89%	89%	87%	91%	79%
NO	19%	9%	4%	36%	11%	11%	13%	9%	20%
OTHER	-	3%	-	1%	-	-	-	-	1%
FRACTION OF COURSES REQUIRING MORE THAN ONE PROJECT	20%	14%	17%	15%	25%	25%	15%	0%	
FRACTION OF COURSES WHERE THE PROJECT IS THE COURSE	7%	5%	9%	8%	0%	13%	0%	0%	
FRACTION OF COURSES REPORTING PROJECT TITLES (OPTIONAL ON QUESTIONNAIRE)	53%	53%	77%	45%	56%	87%	40%	65%	54%

APPENDIX I-6

PERCENTAGE DISTRIBUTION OF INDIVIDUAL OR TEAM APPROACH FOR COURSES WITH DESIGN PROJECTS BY ENGINEERING FIELD

	M.E.	E.E.	A.E.	C.E.	E.	S.E.	E.D.	I.E.	TOTAL
INDIVIDUAL	42%	29%	23%	38%	31%	12%	30%	5%	33%
TEAM	31%	42%	42%	33%	31%	50%	10%	65%	36%
BOTH	27%	26%	35%	28%	38%	38%	60%	30%	30%
OTHER	-	3%	-	1%	-	-	-	-	1%

APPENDIX I-7

PERCENTAGE DISTRIBUTION OF FACULTY OR STUDENT INITIATION OF DESIGN PROJECTS BY ENGINEERING FIELD

	M.E.	E.E.	A.E.	C.E.	E.	S.E.	E.D.	I.E.	TOTAL
FACULTY	41%	36%	35%	68%	31%	25%	40%	20%	44%
STUDENT	13%	11%	23%	4%	31%	12%	15%	30%	13%
BOTH	28%	48%	42%	25%	38%	63%	45%	50%	36%
OTHER	18%	5%	-	3%	-	-	-	-	7%

APPENDIX J

Content of Engineering Design Courses

APPENDIX J-1

PERCENTAGE DISTRIBUTION OF 'YES' RESPONSE TO SELECTED TOPICS COVERED IN ENGINEERING DESIGN COURSES LISTED BY ENGINEERING FIELD (n in parenthesis = number responding yes)

SELECTED TOPIC	M.E.	E.E.	A.E.	C.E.	E.	S.E.	E.D.	I.E.	TOTAL
RELIABILITY	75% (105)	55% (41)	63% (17)	59% (70)	61% (11)	67% (6)	61% (14)	50% (11)	64% (275)
MAINTAINABILITY	46% (65)	37% (28)	56% (15)	50% (59)	44% (8)	56% (5)	35% (8)	50% (11)	46% (199)
DECISION-MAKING	84% (117)	67% (50)	63% (17)	66% (79)	83% (15)	89% (8)	83% (19)	96% (21)	75% (324)
COMPUTER AIDED DESIGN	66% (93)	68% (51)	59% (16)	48% (57)	44% (8)	67% (6)	52% (12)	50% (11)	58% (254)
CREATIVITY	74% (103)	72% (54)	63% (17)	58% (69)	61% (11)	78% (7)	83% (19)	82% (18)	69% (298)
HUMAN RESOURCES	45% (63)	28% (21)	26% (7)	32% (38)	39% (7)	44% (4)	65% (15)	73% (16)	39% (171)
TRADE-OFF STUDIES	61% (86)	63% (47)	82% (22)	53% (63)	61% (11)	89% (8)	61% (14)	77% (17)	62% (268)
SAFETY	65% (91)	36% (27)	70% (19)	61% (73)	39% (7)	44% (4)	52% (12)	55% (12)	57% (245)
OPERABILITY	51% (71)	59% (44)	63% (17)	45% (53)	50% (9)	67% (6)	30% (7)	64% (14)	51% (221)

APPENDIX J-2

AVERAGE AMOUNT(%) OF COVERAGE OF SELECTED TOPICS IN ENGINEERING DESIGN COURSES LISTED BY ENGINEERING FIELD (n in parenthesis = number responding with a percentage) AVERAGED OVER ONLY THOSE COURSES REPORTING A PERCENTAGE

SELECTED TOPIC	M.E.	E.E.	A.E.	C.E.	E.	S.E.	E.D.	I.E.	TOTAL
RELIABILITY	14.4% (68)	7.6% (26)	6.8% (10)	27.8% (38)	8.6% (8)	13.5% (5)	7.2% (9)	8.3% (8)	15.0% (172)
MAINTAINABILITY	8.7% (40)	6.9% (17)	7.2% (9)	17.0% (33)	11.0% (5)	9.4% (4)	6.0% (5)	10.2% (9)	10.7% (122)
DECISION-MAKING	23.5% (75)	16.6% (31)	22.1% (10)	35.2% (44)	38.2% (11)	26.7% (6)	20.8% (13)	18.6% (15)	25.2% (205)
COMPUTER AIDED DESIGN	15.2% (61)	15.9% (34)	24.4% (8)	20.9% (32)	31.7% (6)	12.0% (5)	24.4% (8)	11.3% (8)	17.7% (162)
CREATIVITY	24.8% (67)	21.9% (32)	15.2% (9)	30.4% (37)	23.4% (8)	25.8% (6)	15.0% (13)	12.8% (13)	23.4% (185)
HUMAN RESOURCES	13.6% (37)	6.2% (12)	5.2% (4)	17.8% (25)	15.0% (3)	18.8% (4)	31.0% (10)	19.4% (10)	15.8% (105)
TRADE-OFF STUDIES	16.7% (51)	15.4% (28)	24.6% (12)	22.2% (34)	12.0% (5)	20.8% (6)	9.5% (10)	13.0% (12)	17.4% (158)
SAFETY	11.8% (55)	5.9% (14)	9.7% (10)	26.9% (38)	13.3% (3)	9.4% (4)	6.4% (7)	10.4% (8)	14.7% (139)
OPERABILITY	11.1% (42)	13.8% (23)	10.1% (10)	21.7% (25)	11.3% (4)	16.9% (4)	7.5% (4)	18.5% (8)	14.6% (118)